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Hemodynamic and neuromuscular responses to exercises performed on stable and unstable surface with and without blood flow restriction

Agnelia Tiffany Hernandez
The University of Texas Rio Grande Valley

HEMODYNAMIC AND NEUROMUSCULAR RESPONSES TO EXERCISES PERFORMED ON STABLE AND UNSTABLE SURFACE WITH AND WITHOUT BLOOD FLOW RESTRICTION

BY

AGNELIA TIFFANY HERNANDEZ

A THESIS PRESENTED TO THE GRADUATE FACULTY OF

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APPROVED BY:

Murat Karabulut
Dr. Murat Karabulut
Thesis Director

Eric James
Dr. Eric James
Committee Member

Cheng Chang Pan
Dr. Cheng Chang Pan
Committee Member

Charles Lackey
Dr. Charles Lackey
Dean of Graduate Studies

Graduate School
University of Texas at Brownsville
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Abstract

PURPOSE: The aim of this study was to investigate the acute effects of circuit training exercises on stable and unstable surface with and without blood flow restriction (BFR) on several physiological measures (heart rate, blood pressure, muscle unit activation and rate of perceived exertion). **METHODS**: Sixteen recreationally active, males (age= 24.3 ± 1.2); n=8) and females (age= 23.1 ± 0.9); n=8) completed four testing sessions, no blood flow restriction (NBFR) on a stable surface, NBFR on an unstable surface, BFR on a stable surface, and BFR on an unstable surface. Participants performed lower body exercises in a circuit like routine, which consisted of 6 exercises for 2 rounds. Electromyography (EMG) electrodes were placed at one-third the distance over the longitudinal axis of the vastus lateralis (VL) and half the distance between the greater trochanter and lateral femoral epicondyle over the rectus femoris (RF). For the BFR sessions, BFR cuffs were placed on the upper most portion of the thigh, with an initial restrictive pressure (IRP) of 50 mmHg and a total restrictive pressure (TRP) depended on their leg circumference. **RESULTS**: Generally, a significant ($p < 0.05$) leg main effect for both EMG RMS and MDF values for RF muscle were found and significant ($p<0.05$) surface and time ($p<0.05$) main effects were found for both EMG RMS and MDF values for VL muscle. Repeated measures ANOVA revealed significant differences for surface ($p < 0.05$) and time ($p < 0.05$) for heart rate and systolic blood pressure. Repeated measures ANOVA revealed significant increases in rate of perceived exertion values for the BFR session ($p < 0.01$). **CONCLUSION**: No significant changes in several physiological responses were observed in the present study. However, since the values for several independent variables were generally higher compared to the other conditions,

proper adjustments to the study procedure during circuit and BFR training may provide benefits for cardiorespiratory system, skeletal muscle strength and size. Instability training adds a greater emphasis on trunk muscle activation; therefore, this form of training may also provide a new alternative way of resistance training with a greater emphasis on trunk activation and balance.

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CHAPTER I

INTRODUCTION

Skeletal muscle has the capacity to adjust to mechanical stress, however the response can vary between different modes of exercise (Kay, St Clair Gibson, Mitchell, Lambert, & Noakes, 2000) and the physiological response to exercise may change when basic training principles such as intensity, frequency, and volume are altered (Karabulut M. , Abe, Sato, & Bemben, 2007). An increase of muscle size and strength is caused when training at intensity between 67 and 85% of 1 repetition max (RM) (Baechle & Earle, 2000) with a fairly large volume of repetitions and sets and short rest periods between sets (~1min) (Ishii, Madarame, Odagiri, Naganuma, & Shinoda, 2005). In contrast, exercises with intensities of <65% of 1RM generally stimulates improvements of muscular endurance with no significant increases in muscular size and strength.

The previously mentioned principle seems to be partially relevant for circuit weight training, in which the goal is to gain both muscular strength and endurance concurrently. A type of resistance training with a sequence of exercises performed with short to no rest periods between sets was developed as circuit weight training. Circuit training has been shown to cause strength gains with an intensity of 40-60% of 1RM (Gettman, Ayres, Pollock, & Jackson, 1978; Gettman, Ward, & Hagan, 1982; Wilmore, Parr, & Girandola1978). A study that parallels with this statement was conducted by Takarada et al. (2002), subjects showed an increase in muscular size and strength when performed with a short interest rest period of 30 seconds and an exercise intensity of ~50% of 1RM.

Another type of training used concurrently with resistance training is instability training. Resistance training using balls or unstable platforms has recently had an increase of popularity (Behm & Anderson, 2006). It has been reported that physical therapist use balls for therapy as well as sports training (Behm & Anderson, 2006). In another study, Verhagen et al. (2005) reported a successful use of balance training to decrease the rate of ankle sprain in a group of volleyball players. An efficient means of improving balance and strength may be found with the combination of resistance and instability training (Behm & Anderson, 2006).

Research on resistance training has been increasingly used with BFR. Recent studies have shown that resistance exercise with an intensity as low as 20-50% of 1 RM can efficiently cause increase in muscular hypertrophy and strength (Karabulut, Abe, Sato, & Bemben, 2010) when combined with moderate restriction of blood flow (Ishii, Madarame, Odagiri, Naganuma, & Shinoda, 2005; Takano, et al., 2005; Takarada, et al., 2000). This type of resistance exercise with vascular restriction, termed KAATSU training, generally has been shown to suggest an increase in muscle fiber recruitment and enhanced endocrine responses both of which are related to the hypertrophic effect on muscle. Vascular restriction stimulates exercise induced responses such as greater muscle activation (James & Karabulut, 2013). James et al. (2013) found that BFR training lead to a slower increase in electromyography (EMG) regularity compared to the non BFR training. It was known that the neuromuscular system adapts to both chronic and acute physical stress (Karabulut & Perez, 2013). However, no research has been conducted with all previously mentioned variables of resistance training.

The present study will focus on the acute effects of circuit training exercises with and without BFR on heart rate, blood pressure, rate of perceived exertion and muscle unit activation on stable and unstable surfaces. This study may also indicate that the combination of BFR training with different modes of training programs, in this case a BOSU ball and circuit-type training, may also be used to increase motor unit activation and the level of neuromuscular adaptation. Completing this study may also help research if this is a better technique or a possible alternative fitness exercise.

Study Purpose

The purposes of the study are: 1) to examine the acute effects of circuit training exercises with and without BFR on heart rate, blood pressure, and rate of perceived exertion; 2) To examine the changes in motor unit activation and motor unit action potential firing frequency in response to exercises performed on stable and unstable surface with and without BFR; 3) to investigate the differences between genders on the previously stated measures.

Research Questions

1. Which measure, without BFR or with BFR on stable or unstable surface, will cause a significant difference in heart rate, blood pressure, and rate of perceived exertion?
2. Will the unstable surface have significant differences on changes in motor unit activation and motor unit action potential firing frequency in response to exercises performed on stable and unstable surface with and without BFR?

3. Will the male participants results be significantly different compared to the female participants?

Hypotheses

1. Hypothesis to be tested is BFR training on unstable surface will cause significantly higher heart rate and blood pressure as well as a greater rate of perceived exertion compared to other conditions.
2. Hypothesis to be tested is with an increase in instability, muscle activation will increase. Instability with BFR on an unstable surface condition will have a greater muscle activation increase compared to the other conditions.
3. Male participants will be significantly different compared to female participants.

Significance of the Study

A training method, which restricts muscular blood flow during training, has tested many of the already accepted principles of exercise training and has demonstrated that this method may be an efficient technique as well as effective alternative training to improve the quality of life. BFR changes in both normal population and the elderly have been shown to be efficient in causing training-related positive physiological changes such as cardiovascular fitness, skeletal muscle strength, and skeletal muscle size. It has been well documented that BFR training modality can improve aerobic capacity, skeletal muscle strength, and skeletal muscle size by using lower load and decreased exercise time requirement per session (15-20min) compared to high intensity traditional training modalities. Therefore the aim of the proposed study is to determine if the unstable surface will affect any measures (heart rate, blood pressure, and rate of perceived exertion) with

BFR during a circuit training regimen. Research has been conducted on BFR, circuit training, and performing exercises on stable surfaces compared to unstable surfaces. Yet, insufficient research has been conducted on all three factors used at once. This study can also assist in questions regarding the understanding of this possible new fitness technique. Exercise intensity needed to potentiate physiological improvements in skeletal muscle strength and size has greatly reduced due to BFR training (Sakamaki, Fujita, Sato, Bemben, & Abe, 2008; Takano et al., 2005; Takarada, Takazawa, Sato, Takebayashi, Yasuhiro, & Ishii, 2000).

Although recent studies have stated that BFR training has significant benefits in skeletal muscle size and strength, little is known about the acute effects of circuit training exercises with and without BFR on different surfaces (unstable and stable) on heart rate, blood pressure, rate of perceived exertion and muscle unit activation. Therefore, there is a need for further research to investigate whether the surface stability affects different measures when performing circuit training exercises. The data from this proposed research will provide detailed information on the effectiveness of this novel technique and allow researchers to design training studies to incorporate the unstable surface in a variety of BFR exercises.

Delimitations

1. Only students who are recreational active participated in the study.
2. Only participants between the ages of 18-40 participated in the study.

3. The exclusion of individuals with disabilities or diseases preventing them from being strength tested and trained, including hypertension and cardiovascular diseases.
4. The exclusion of individuals with chronic back or joint problems.
5. The exclusion of individuals outside of the 18-40 year age range.

Limitations

1. It was not a random sample and all participants were volunteers; therefore, they may not be representative of the actual population.
2. Although participants provided medical clearance, medical information and health history were obtained through self-report.
3. Although participants were asked not to change their normal daily activities, daily activities performed outside of the training program are not controlled.

Assumptions

1. All individuals performed all exercises to the best of their ability.
2. All individuals performed all exercises with correct form.
3. Accurate information was provided by each participant regarding medical and health history.
4. The equipment used was reliable and provided accurate information for all testing sessions.

Operational Definitions

The following definitions were used in this study and are presented here for clarification:

Blood Flow Restriction (BFR): BFR is a technique that restricts muscular blood flow during low-intensity exercise training. This process involves cuffs placed carefully to reduce blood flow to the designated limb. Specially designed elastic belts (50 mm wide) that are filled with air to create pressure are used to restrict blood flow to the lower extremities.

BOSU ball: Can be described as half ball with a flat surface on one side and a hemisphere surface on the other. "BOth Sides Utilized (Up)," meaning that this piece of equipment may be used on either side, flat side up or dome side up.

Diastolic Blood Pressure (DBP): Arteriole pressure between heart beats.

Electromyography (EMG): Recording electrical activity of the muscle tissue using electrodes attached to the skin.

Exercise: Repetitive bodily movement on varying levels exertion that is performed to develop, maintain or improve one or more components of physical fitness.

Hemodynamic: Is the study of blood circulation and blood flow.

Initial Restrictive Pressures: The tightness of cuff before inflated with air.

Physical Activity Readiness Questionnaire (PAR-Q): PAR-Q is designed to identify the small number of adults for whom physical activity might be inappropriate or those who should have medical advice concerning the type of activity most suitable for them.

Ratings of Perceived Effort (**Borg's Scale):** The subjective assessment of exercise based on how the participant feels.

Systolic Blood Pressure (SBP): Arteriole pressure when the heart beats.

Total Restrictive Pressure (TRP): The tightness of cuff after inflated with air.

Unstable surface: Is operationally defined as “BOSU ball”.

CHAPTER II

REVIEW OF LITERATURE

Blood Flow Restriction (BFR Training)

BFR training, also known as KAATSU training, has been shown to allow the elderly, athletes and obese population exercise at a lower intensity and still obtain high intensity results while exercising. Over the past 10 years, clinical research has demonstrated that BFR training not only improves muscle strength and mass in healthy subjects but also benefits patients with cardiovascular and orthopedic conditions (Sato, 2005). In Japan, this training is valued as “high technological invention utilizing the laws of nature,” (Sato, 2005).

BFR training is a method that restricts the blood flow using relatively light and flexible cuffs placed on the proximal part of one’s lower or upper limbs while an individual is performing exercise at a low intensity. The cuffs provide the proper amount of pressure needed for each exercise. This type of training continues to grow as researchers continue to study the effects of BFR training has on multiple physiological systems. Research initiated by focusing on the effects of acute low intensity BFR exercise on blood growth hormone and the chronic effect on muscle hypertrophy and strength gains in addition to the effects of BFR training on muscle size and strength in athletes (Takarada, Takazawa, Sato, Takebayashi, Yasuhiro, & Ishii, 2000). The results were published in significant research journals which continue to draw vast attention from the public.

Responses to Aerobic Training with BFR

Sakamaki et al. (2008) has reported a slight but not a significant increase in heart rate (HR) in response to BFR walk training. The study examined blood pressure and heart rate response to walking with and without BFR in 2 men and 5 women aged between 64 to 78 years. All participants performed a 20 minute walking test at 4 km/hr without (Control) and with BFR cuff pressures 160 mmHg and 200 mmHg on separate days. No significant differences in blood pressure responses to the walk exercise between the Control and BFR -160mmHg exercise were observed, yet significantly higher blood pressures were observed for the BFR-200 mmHg exercise (112-127 mmHg for mean arterial blood pressure) compared to the Control. Heart rate responses were higher in both BFR pressures compared to the control group, but were not significantly different. HR and mean arterial blood pressure (MAP) were significantly correlated between each pressure with a higher MAP response to the same HR at the 200 mmHg pressure. Significant increases in MAP are dependent on total restrictive pressure (TRP). Due to the greater increase of peripheral resistance in the lower extremities at a TRP of 200 mmHg by the application of the cuff may be a factor of a significant increase ($p < 0.01$) in MAP since significant increases were reported at a TRP of 160 mmHg in the last four minutes of exercise. These findings are parallel with the thought that occlusive pressure alone can significantly alter the cardiovascular responses during low-intensity KAATSU-walk. Significantly greater oxygen uptake and HR were recorded during slow treadmill walking with BFR than during walking without BFR (Abe, et al., 2010). The innovation of BFR appears to be the unique combination of venous blood volume pooling and restricted arterial blood inflow. With this combination, it can result in a decreased stroke volume and increased HR while maintaining cardiac output. However, as a result of increased HR at the same systolic blood pressure (SBP) during exercise with BFR, a high mechanical stress on the heart may be produced, as indicated by a greater rate-pressure product ([HR*SBP]/100) (Abe, et al., 2010). Volume of BFR training is less in comparison to traditional endurance exercise with similar improvements in VO2 Max. Aerobic BFR training studies have shown to increase cardio respiratory fitness (CRF) along with increasing fat free mass (Abe, Keams, & Sato, 2005; Ozaki, et al., 2011). Ozaki et al. (2011) examined the effects of walk training combined with BFR on muscle hypertrophy as well as on peak oxygen uptake (VO2peak) in 18 sedentary women (57–73 years). Training program consisted of participants in both the BFR-Walk and CON-Walk groups performed 20 minutes of treadmill walking at 45% of heart rate reserve for four days a week for ten weeks. Aerobic capacity was measured via a bicycle graded exercise test (GXT) using an automated breath-by-breath mass spectrometry system. BFR training yielded significant improvements ($p < 0.01$) in VO2 peak and muscular size and strength in comparison to the control group. BFR walk training demonstrated that both muscle volume and strength increased in older women. Changes in body mass index were reported however significant differences were not observed.

Abe et al. (2010) examined the effects of low-intensity cycle exercise training with and without BFR on muscle size and maximum oxygen uptake (VO2max) in 19 young men (mean age ± SD: 23.0 ± 1.7 years) whom trained for 3 days/wk for 8 wk at an intensity and duration of 40% VO2max and 15 minutes for the BFR-training group and 40% of VO2max and 45 minutes for the CON-training group. Significant improvements were seen in VO2max ($p < 0.05$), muscle cross sectional area and muscle volume ($p < 0.01$) and isometric knee extension strength ($p < 0.10$) between groups. Abe et al. (2010) suggested that with a low-intensity, short-duration cycling exercise combined with BFR improves both muscle hypertrophy and aerobic capacity concurrently in young men.

Another study performed by Abe et al. (2005) investigated the acute and chronic effects of walk training using KAATSU on muscle size, strength and blood hormonal parameters. Eighteen men were split between the control group with NBFR and the KAATSU walking group with BFR. The training was performed two times a day for 6 days out of the week for 3 weeks. Subjects performed 5 sets of 2 minute bouts with a 1 minute rest between each bout (treadmill speed was set at 50 m/min). Results obtained displayed that with the combination of leg muscle BFR and slow walk training will induce muscle hypertrophy and strength gain, regardless of the low level of exercise intensity. BFR walk training may be a useful method for promoting muscle hypertrophy, including a wide range of the population such as delicate and elderly (Abe, Kearns, & Sato, 2005).

Responses to Resistance Training Exercise with BFR

Takano et al. (2005) examined eleven untrained males (26–45 years) and their hemodynamic and hormonal responses to a short-term, blood flow restricted low-intensity resistance exercise. The subjects performed bilateral leg extensions at 20% of 1RM for a set of 30 repetitions. After a 20 second rest, participants performed three additional sets until exhaustion. The total restrictive pressure (TRP) during the training was set to 160mmHg-180mmHg. Both blood pressure and maximum heart rate were significantly higher in the BFR participants than in the NBFR group. Venous return decreased causing a reduced both stroke volume and cardiac preload. These results suggest that short-term low-intensity resistance exercise with KAATSU significantly stimulates the exercise induced growth hormone, vascular endothelial growth factor, and insulin-like growth factor responses with the decrease of cardiac preload during exercise. This may become an alternative and unique method for rehabilitation in patients with cardiovascular diseases (Takano et al., 2005). Takano et al. (2005) also states that blood pressure and heart rate significantly increased in BFR resistance training compared to the control group.

Takarada et al. (2005) studied the effectiveness of relatively low-intensity resistance exercise training combined with moderate vascular occlusion in elderly women. Twenty-four healthy postmenopausal women (47-67 years) performed a 16 week resistance exercise regimen with occlusion. Subjects performed single arm dumbbell curl exercises in a sitting position. Using the non-dominant arm subjects kept their upper body upright and the upper arm inclined at about 45 degrees in front of the body. Results showed that resistance exercise at intensity even lower than 50% 1 RM is effective in inducing muscular hypertrophy and increase in strength when combined with vascular occlusion (Takarada, Takazawa, Sato, Takebayashi, Yasuhiro, & Ishii, 2000). However, Karabulut et al. (2010) examined several studies to compare and research the effects of different initial restrictive pressures on tissue oxygenation. Initial restrictive pressure (IRP) can be described as the tightness of the KAATSU cuff before inflation. The data showed how the IRP of the restrictive cuffs affected the amount of venous return and tissue oxygenation. This specified the importance of initial pressure to influence the amount of blood and metabolite accumulation, which may be a factor responsible for varying findings from previous BFR training studies.

Teramoto et al. (2006) also investigated the effects of low-intensity exercise on muscular fitness when performed with BFR. Nineteen college female and male students completed a 5 week study where they each needed to perform 2 sets of a 5 minute step exercise using a 12 inch bench, 3 times per week. One leg was restricted during the step exercise while the other leg was not occluded. Similar to previously mentioned studies, results for study showed a significantly increase in muscular strength in the BFR leg compared to the non BFR leg. Muscle endurance and mass were also improved however, legs were not significantly different. This method has the potential to be a different form of training to increase muscular strength (Teramoto & Golding, 2006).

Responses to Resistance Circuit Training Exercise with BFR

Ishii et al. (2005) studied the acute effects of moderate venous occlusion on circuit training with body weight alone. Twenty-two healthy females were randomly assigned into two groups, the occlusive training group (OCC) and the normal training group (NOR). In both groups, the same circuit training regimen was performed which consisted of six different yet consecutive exercises for muscles in both upper and lower limbs. All exercises were performed in a step by step process with a brief rest period of 10 seconds. Subjects completed this regimen 3 times per week with each session lasting about 5-10 minutes. The BFR cuffs were placed with a present pressure of 50-80 mmHg for the upper body and 80-120 mmHg for the lower body respectively. An increase of mean muscle cross sectional area of both left and right limbs was displayed at about 3% in the BFR group compared to the control group. The results for this study indicated that with BFR, circuit training with only body weight can cause hypertrophy in lower-limb muscles (Ishii, Madarame, Odagiri, Naganuma, & Shinoda, 2005).

Circuit Training

Circuit weight training is described as an exercise method thought to stimulate systems that promote both cardiovascular and strength benefits (Romero-Arenas, Martinez-Pascual, & Alcaraz, 2013). Researchers have shown that circuit based resistance training is effective in increasing maximum oxygen consumption, maximum pulmonary ventilation, functional capacity and strength while improving body composition (Romero-Arenas, Martinez-Pascual, & Alcaraz, 2013). When prescribing a circuit training protocol, several guidelines should be followed such as: performing 6 to 10 exercises for 1 to 3 sets for a minimum of twice per week (Romero-Arenas, Martinez-Pascual, & Alcaraz, 2013).

Instability Training

A fundamental component of almost every physical movement involves maintaining balance. Balance is a natural skill that involves coordination of muscles, but it can also be learned. The body is able to stabilize in a specific position with balance which also has both sensory and anatomic components. Proprioception is referred to as the awareness of the body movement and orientation to the positioning of the body in space (Ruiz & Richardson, 2005). The brain receives continuous information regarding the body symmetry which is possible through the coordination of synergism. In order to maintain balance, the body uses several somatic sensory receptors such as the muscle spindle fibers, Golgi tendon organs, vision and vestibular system of the inner ear (Powers & Howley, 2009). A person's orientation in space can also be processed in the cerebral cortex which is synthesized using visual cues somatic sensory awareness of joints and vestibular input. In instability training, proprioception in limbs and body is enhanced due to the stress placed on the vestibular and vision receptors which will cause an increase in balance. Injuring of the ankle, knee and lower back can be reduced by training these systems to work efficiently (Ruiz & Richardson, 2005).

Heikamp et al. (2001) studied the ability to quantify the possible gain in strength by balance training in comparison to strength training. Thirty subjects participated in the study where half were randomly assigned to the strength training program group and the other 15 were assigned to the balance training program group. Both groups trained 2-3 times/week for 4-6 weeks until 12 training units were completed. The results indicate balance training to be effective for gain in muscular strength and secondly in contrast to strength training, equalization of muscular imbalances may be achieved after balance training (Heikamp, Horstmann, Mayer, Weller, & Dickhuth, 2001).

The application of balance training with resistance training has been successful in reducing the incidents of ankle sprains in a group of volleyball players (Behm & Anderson, 2006). The balance and controlling of free weights force the individual to stress as well as coordinate more stabilizing, synergist and antagonist muscle groups. However, a study suggests that "the optimal method to promote increases in balance, proprioception and core stability for any given sport is to practice the skill itself on the same surface on which the skill is performed in competition," (Behm & Anderson, 2006).

Conclusion

Previous studies have reported improvements in aerobic capacity and body composition to be influenced by traditional endurance training five days or more a week for 30-60 minutes at 40%-60% VO2. Resistance training at 65%-85% of one repetition maximum elicits a strength and hypertrophic response. The main focus of BFR training centers on the concept of inducing a hypertrophic and strength response with a decrease in exercise volume. With the proper total restrictive pressure, BFR influences blood pressure and heart rate response similar to traditional exercise which may allow individuals with health concerns such as obesity and cardio vascular disease (CVD) to safely participate in an exercise regimen. This new method may provide a new fitness training modality since previous traditional endurance exercises are known to improve skeletal musculature along with cardio respiratory fitness (CRF). Likewise, CRF can be significantly improved with aerobic BFR training at a lesser exercise volume. Low intensity BFR walk training studies have reported improvements in aerobic capacity, strength and muscle size concurrently in older adults and the healthy population (Abe, et al., 2010; Abe, Keams, & Sato, 2005; Ozaki, et al., 2011; Sakamaki, Fujita, Sato, Bemben, & Albe, 2008). Circuit training and instability training provide alternative modes of exercise and have both shown improvements in muscular strength (Ishii, Madarame, Odagiri, Naganuma & Shinoda, 2005; Behm & Anderson, 2006). The acute effect of circuit-like BFR training on an unstable surface has not yet been investigated and this investigation may be useful to provide details on BFR training as an alternate mode of exercise.

CHAPTER III

METHODS

Subjects

Eight healthy women and eight healthy men between the ages of 18 and 40 were recruited for this study. Subjects were classified as recreationally active or athletic. This study was a within subject design. All subjects attended all five sessions for this study which were the familiarization session, the NBFRS, NBFRU, BFRS and BFRU. All subjects were fully informed about the purpose of the study and the possible risks involved, and gave their written informed consent. The study procedure that was approved by the University of Texas-Brownsville Institutional Review Board for Human Subjects was followed.

Inclusion Criteria

1. Subjects who were considered recreationally active as defined by performing physical activity 3 to 5 times a week on a consistent basis.
2. Subjects who were within 18-40 years of age.
3. Subjects who had no chronic back or joint problems.

Exclusion Criteria

1. Subjects who were not considered recreationally active as defined by performing physical activity 3 to 5 times a week on a consistent basis..
2. Subjects that were taking medication known to affect blood pressure.
3. Subjects that were taking medication known to affect heart rate.

Recruitment

Male and female subjects were recruited through word of mouth, social media, e-mails and flyers posted throughout the University of Texas Brownsville campus with detailed information about the study. Subjects were contacted via email, text to phone number or on Facebook (social media page) group named “Thesis Participants”. All participants were added to the private Facebook group for quicker communication. Participants were given a schedule to meet at a certain time each day at the University of Texas-Brownsville Exercise Science Biomedical Lab.

Experimental Protocol

All subjects performed a randomized circuit-training regimen consisting of six successive exercises for major muscle groups in the lower limbs and the trunk. The exercises that were performed are the following: knee up right leg, knee up left leg, super skater right leg, super skater left leg, body squat, and alternating side lunge. All exercises were performed in a step-by-step fashion essentially without a rest period, though a brief interval of ~ 15 seconds was typically required to prepare for the next exercise. The frequency of exercise was 3 sessions per week with a 48 hour separation between all the conditions, respectively. The repetitions in each exercise and the round number stayed the same as the training proceeds. In the first condition, the subjects performed the entire session of exercise lasting typically for 15 minutes (2 rounds) with no BFR on a stable surface. In the second condition, the subjects performed the entire session of exercise with no BFR on an unstable surface. In the third condition, the subjects performed the entire session of exercise with BFR on a stable surface. In the fourth condition, the subjects performed the entire session of exercise with BFR on an unstable surface. The proximal ends of the lower limbs of the both legs were moderately compressed to restrict the venous blood flow by means of elastic belts attached to the shorts or pants. Conditions were randomized as well as the order of the circuit like training exercises for each subject.

Electromyography (EMG) Recordings

Surface EMG electrodes were placed along the longitudinal axis of the VL and RF of the right and left thigh. Subjects were asked to sit down on the floor or bench with one leg fully extended the other bended at the knee and leaning back on their hands. Two large towels are rolled up and placed one above the other underneath the knee of the fully extended leg. Slight pressure was applied on subjects shin while the subject was asked to kick upward towards the pressure. This exposed the two leg muscles, VL and the RF which were needed to obtain the proper measurements for the correct electrode placement on each leg. The electrode placements on the VL were placed to a mark that was made at 33.3% and RF at 50% of the distance from the lateral femoral epicondyle to the greater trochanter. The ground electrode was placed over the bony part of the patella. The orientations of both electrodes were placed along the longitudinal axis of femur. The skin was shaved, lightly abraded, and cleaned with isopropyl alcohol to reduce the electrode-skin impedance. After skin preparation, two DE-2.3 sensors (Delsys Inc., Boston, MA) were placed over the belly of the VL muscle; with disposable adhesive electrodes. The electrodes were secured to the skin using adhesive tape (Mueller Sports Medicine, Inc., Prairie du Sac, WI, USA) to minimize artifact movement. Shorts were taped high enough to not disturb the electrodes that are placed on each leg.

Leg Circumference

Subjects leg circumference was measured beginning at 50% of the distance from the lateral femoral epicondyle to the greater trochanter. From this measurement, the tape measure was placed to surround the thigh and the proper measurement was recorded. BFR KAATSU cuffs were placed in the most proximal portion of the legs around the inguinal area. The pneumatic bags are along the inner surface of the elastic belts and connected to an electronic air pressure control system (KAATSU-Master, Sato Sports Plaza, Tokyo, Japan). After determining the total restrictive pressure (TRP) by leg circumference each participant was seated and the BFR cuff was set the constant initial restrictive pressure of 50 mmHg. The cuffs were then inflated to reach the approximate normal resting systolic blood pressure (120 mmHg) for a healthy adult. The inflated cuff pressure was relative to the subjects' thigh circumference. Research proposes that the thigh circumference is the biggest predictor of arterial occlusion pressure during supine rest. Loenneke JP et al. (2012) plotted thigh circumference with arterial occlusion to determine an estimated arterial occlusion pressure for each subject. For the BFR protocol, an inflation pressure of 60 % of the subjects' predicted arterial occlusion pressure to ensure that the inflated cuff pressure would not cause arterial occlusion (<45–50 cm = 120 mmHg; 51–55 cm = 150 mmHg; 56–59 cm = 180 mmHg; and ≥60 cm = 210 mmHg). The initial pressure was held for 30 seconds and released for 10 seconds. Then the pressure was increased by 20 mmHg while holding for 30 seconds at each pressure and releasing for 10 seconds between increments until the target restrictive pressure (between 120 and 210 mmHg) was reached. The BFR cuffs target pressure was maintained throughout the testing session. The total time that the cuffs stayed inflated was between 10-20 minutes.

Borg's Rating of Perceived Exertion Scale (RPE)

RPE was used to subjectively measure an individual's physical activity intensity level fatigue using Borg's 0 to 10 scale. RPE was recorded after each exercise throughout testing session for 15 minutes for a total of 12 recordings. Perceived exertion ratings between 3 and 6 are indicators of moderate intensity.

Cardiovascular Measures

Heart rate was monitored during testing session after each exercise for a total of 12 recordings with a Polar Heart Rate monitor E600 Series. Systolic blood pressure (SBP) and diastolic blood pressure (DBP) was recorded using the blood pressure (BP) machine. BP was recorded from the upper left arm post testing session (immediately, 3, 4, 6, 8 minutes after session) for a total of 5 recordings using an automatic blood pressure reader.

Signal processing

The EMGworks 3.7 analysis software (2009, Delsys Inc., Boston, MA, USA) was used to analyze neuromuscular function. EMG signals were amplified and recorded by a BagnoliTM 8-channel system (Delsys Inc., Boston, MA). The average RMS and MDF for VL and RF were computed for each 5 contractions (4 measures for squat exercise, 2 measures for the rest of the exercises).

Statistical analysis

The Microsoft Excel program (2003, Microsoft Corporation, Seattle, WA, USA) was used to compile the main results database. Statistical analyses were computed using SPSS 17.0 for Windows (SPSS Inc., Chicago, IL). Data was expressed as means ± SE. For all statistical analyses, significance was accepted at $p < 0.05$.

Data was expressed as means ± SE. Repeated measures ANOVAs was used to test mean differences in the variables tested (surface (stable vs. unstable)*blood flow (restricted vs. non-restricted*leg (right or left)*time (4 for all other exercises or 8 for squat) * time). Bonferroni post-hoc comparisons were used to assess the difference between means when a significant difference was detected. The level of statistical significance was set at $p < 0.05$.

CHAPTER IV

RESULTS

The purposes of the study was threefold: 1) to examine the acute effects of circuit training exercises with and without BFR on heart rate, blood pressure, and rate of perceived exertion; 2) To examine the changes in motor unit activation and motor unit action potential firing frequency in response to exercises performed on stable and unstable surface with and without BFR; 3) to investigate the differences between genders on the previously stated measures.

Subject Characteristics

Sixteen young, recreationally active male (age= 21.9 ± 0.8), n=8) and female (age= 23.1 ± 0.9), n=8) subjects participated in this study. Significant differences Table 1 shows participants descriptive measures. Recreationally active is defined by performing physical activity 3 to 5 times a week on a consistent basis prior to recruitment. Participants were recruited from the University of Texas-Brownsville community.

Table 1. Descriptive Measures.

Variables	Male (n=8)	Female (n=8)	Combined (n=16)
Age (yr)	21.9 (0.8)	23.1 (0.9)	22.5 (0.6)
Height (cm)	172.9 (1.3)	161.9 (1.7)	167.4 (1.8)
Weight (kg)	83.5 (4.8)	65.5 (3.0)	74.5 (3.6)
Resting HR (beats/min)	73.9 (3.3)	71.6 (3.1)	72.8 (2.2)
Resting SBP (mmHg)	126.3 (3.8)	102.8 (4.1)	114.5 (4.1)
Resting DBP (mmHg)	70.8 (2.2)	60.4 (3.0)	65.6 (2.2)

HR (Heart Rate); SBP (Systolic Blood Pressure); DBP (Diastolic Blood Pressure)
Values reported as mean ± SE. N = 16.

Cardiovascular Response

Subject participation varied in the immediate post exercise blood pressure values due to a quick adjustment made during the testing sessions. All other categories had the complete sixteen recreationally active subjects. Subject participation is displayed in Table 2.

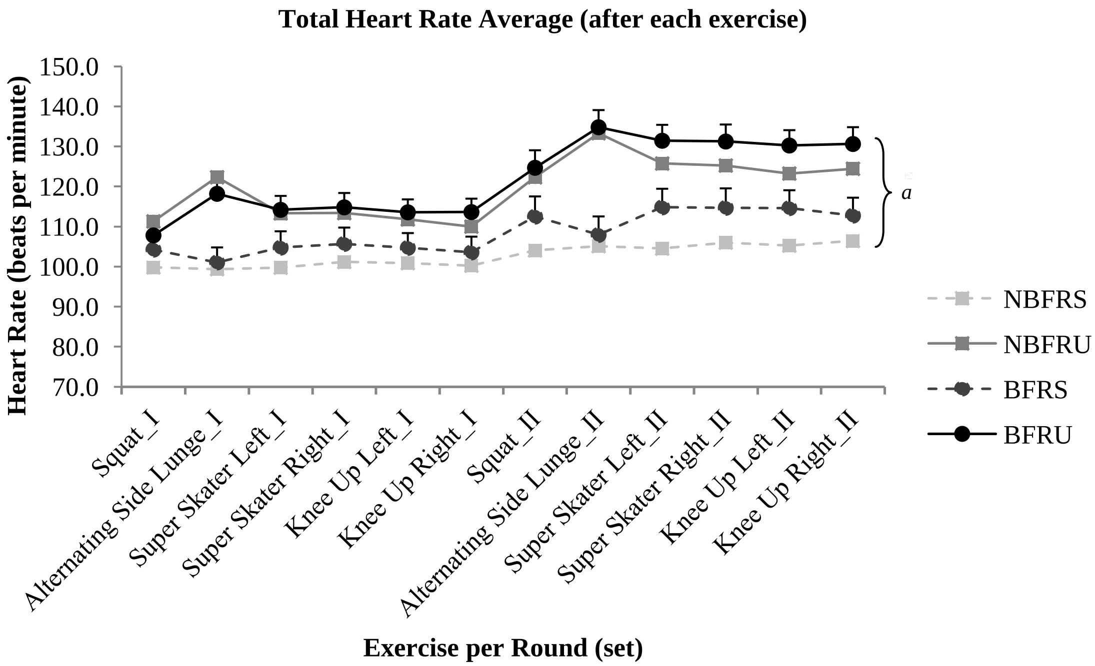
Table 2. Total Blood Pressure Measures.

	NBFRS	NBFRU	BFRS	BFRU
Immediately	N=13	N=9	N=14	N=15
3 minutes	N=16	N=16	N=16	N=16
4 minutes	N=16	N=16	N=16	N=16
6 minutes	N=16	N=16	N=16	N=16
8 minutes	N=16	N=16	N=16	N=16

No blood flow restriction on a stable surface (NBFRS); No blood flow restriction on an unstable surface (NBFRU); Blood flow restrictions on a stable surface (BFRS); Blood flow restrictions on an unstable surface (BFRU).

Figure 1 shows a time course response of the total average heart rate (HR) at the end of each exercise for all four testing sessions, NBFRS, NBFRU, BFRS, and BFRU. Repeated measures ANOVA found a significant increase in HR ($p < 0.05$) throughout testing session for all conditions. A greater HR response was observed in the BFR unstable (BFRU) surface. There was a significant three-way interaction between surface*leg*gender ($p=0.021$), surface*leg*time ($p=0.018$), blood flow*time*gender ($p=0.016$) and blood flow*leg*time ($p=0.016$). There was a significant two-way interaction between leg*time ($p=0.015$).

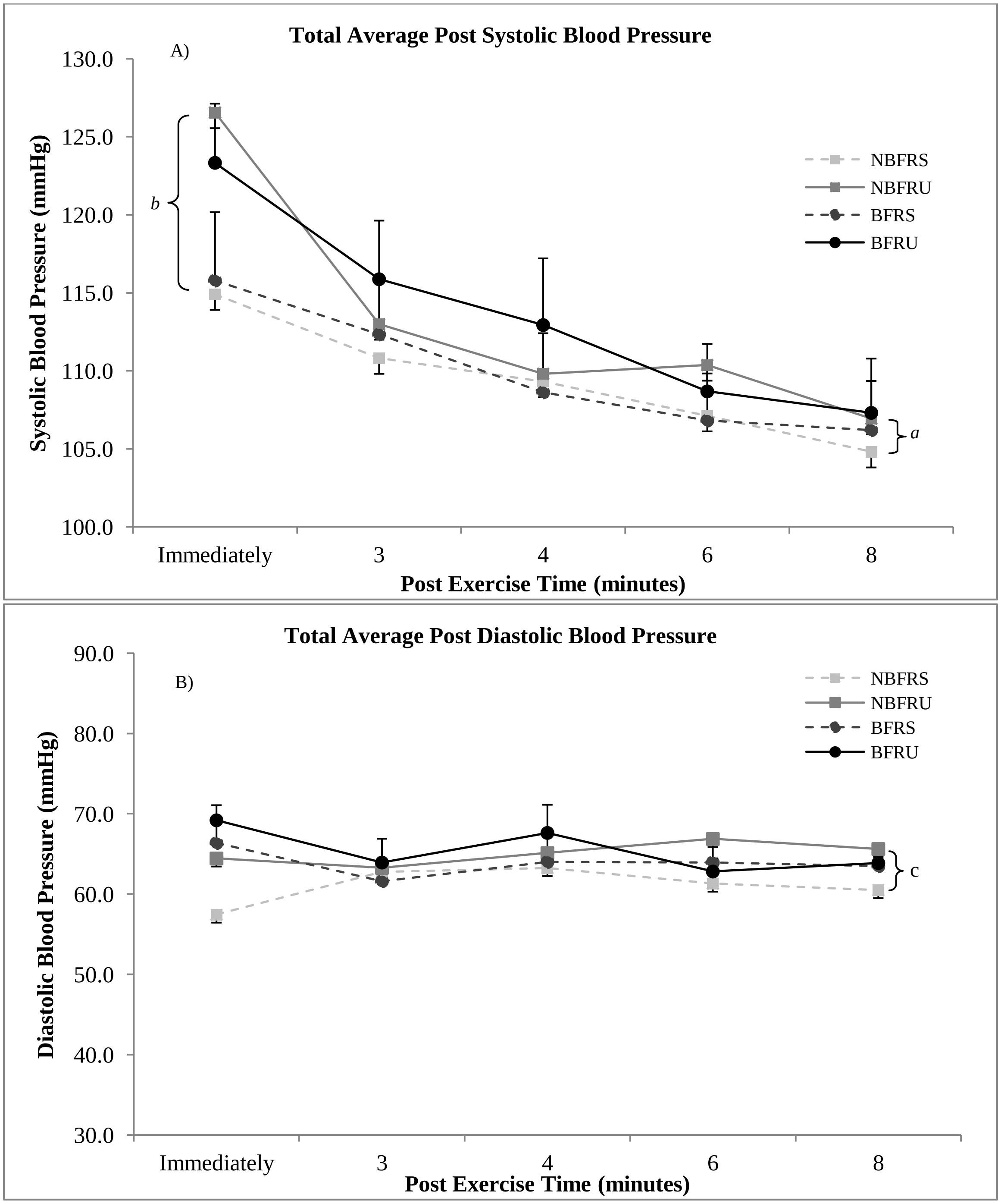
Figure 1. Total average of heart rate (HR) response.



[a] represents time difference within all conditions (p<0.05). Values reported as mean ± SE. N=16.

Figures 2A illustrates systolic blood pressure (SBP) responses and figure 2B illustrates diastolic blood pressure (DBP) to different conditions (NBFRS, NBFRU, BFRS, BFRU) after the circuit-like training. Two significant main effects for surface (p=0.025) and time (p<0.01) were found for SBP. A significant gender main effect was found in DBP (p=0.018).

Figure 2. Total average of blood pressure (BP) response.

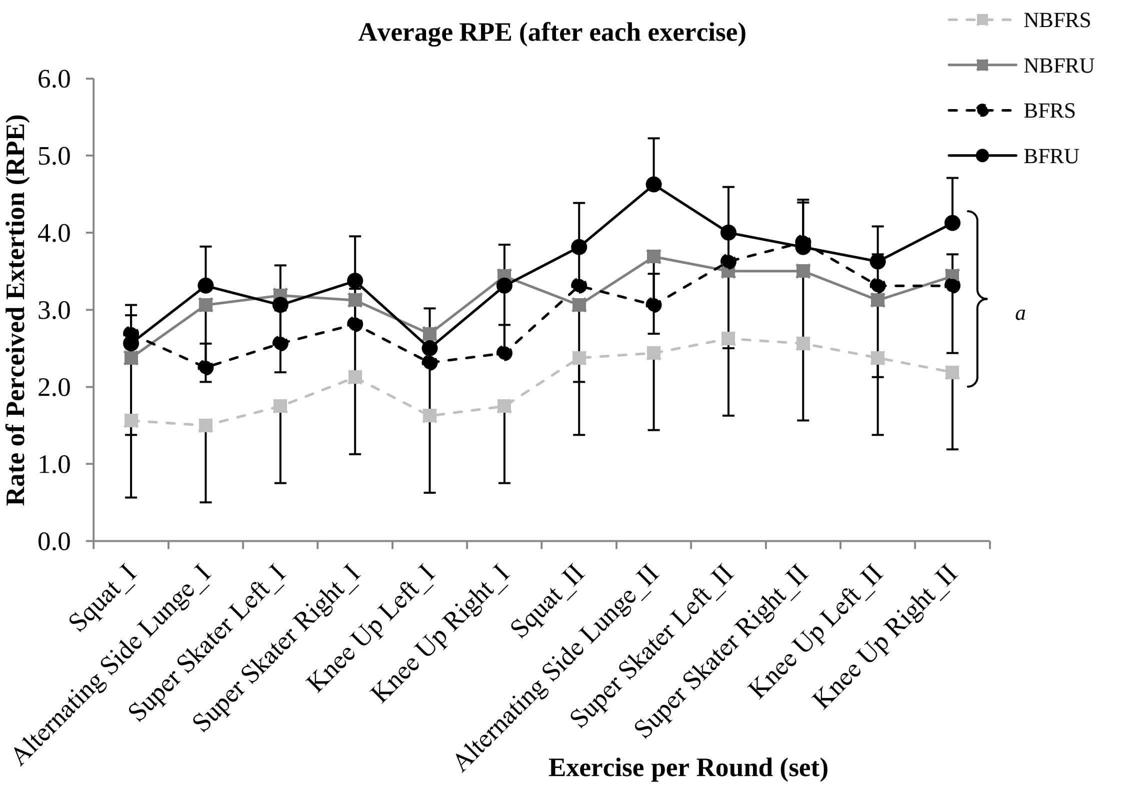


[a] represents time difference within all conditions (p<0.05); [b] represents surface difference within all conditions (p<0.05); [c] represents gender difference within all conditions (p<0.05); Values reported as mean ± SE.

Subjective Performance

Repeated measures ANOVA detected a time ($p < 0.05$) main effect in RPE (Fig. 3). Several significant three-way interaction were detected, surface*leg*gender ($p = 0.021$), surface*leg*time ($p=0.018$), blood flow*time*gender ($p=0.016$), and blood flow*leg*time ($p=0.031$). A significant two-way interaction in leg*time was detected ($p=0.015$). RPE progressively increased during exercise with no significant difference between conditions.

Figure 3. Total average of rate of perceived exertion (RPE) response.

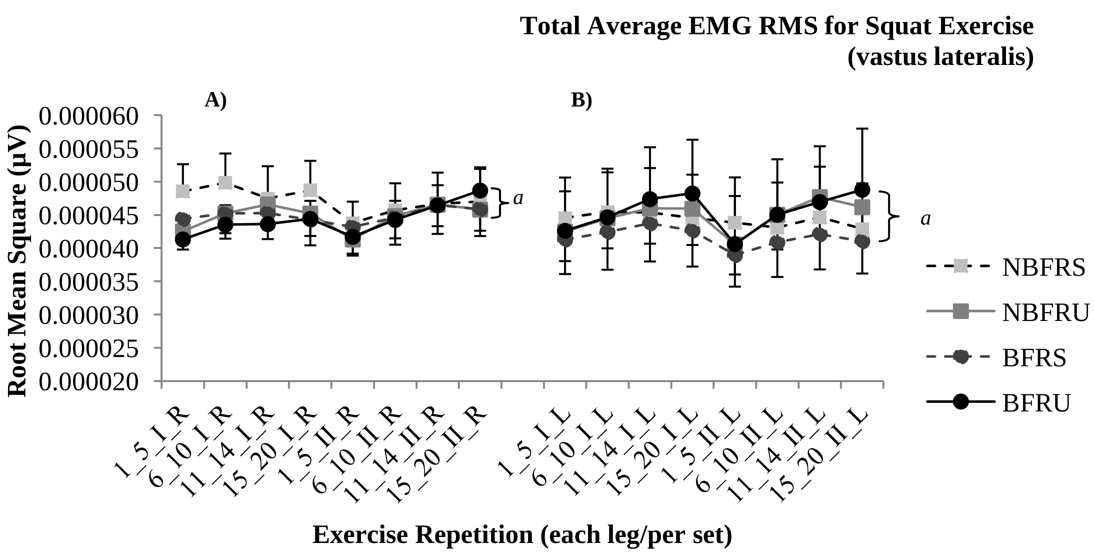


[a] represents time difference within all conditions ($p<0.05$). Values reported as mean ± SE. N=16.

Muscle Function

Electromyographic (EMG) recordings of the vastus lateralis (VL) and rectus femoris (RF) were collected from both right and left leg on sixteen young, recreationally active male (age= 21.9 ± 0.8, n=8) and female (age= 23.1± 0.9, n=8) subjects from the same group shown in Table 1. Figure 4 displays the average EMG RMS values for VL muscle during squat exercise for both rounds (sets) per each 5 repetitions across the dynamic exercise repetitions with all 4 conditions (NBFRS, NBFRU, BFRS, BFRU) for (A) right leg and (B) left leg. A time (p=0.014) main effect for EMG RMS was detected by repeated measures ANOVA. There was a significant three-way interaction between surface*leg*gender (p=0.021), surface*leg*time (p=0.018), blood flow*time*gender (p=0.016), blood flow*leg*time (p=0.031) and there was a significant two-way interaction for leg*time (p= 0.015) (Figure 4).

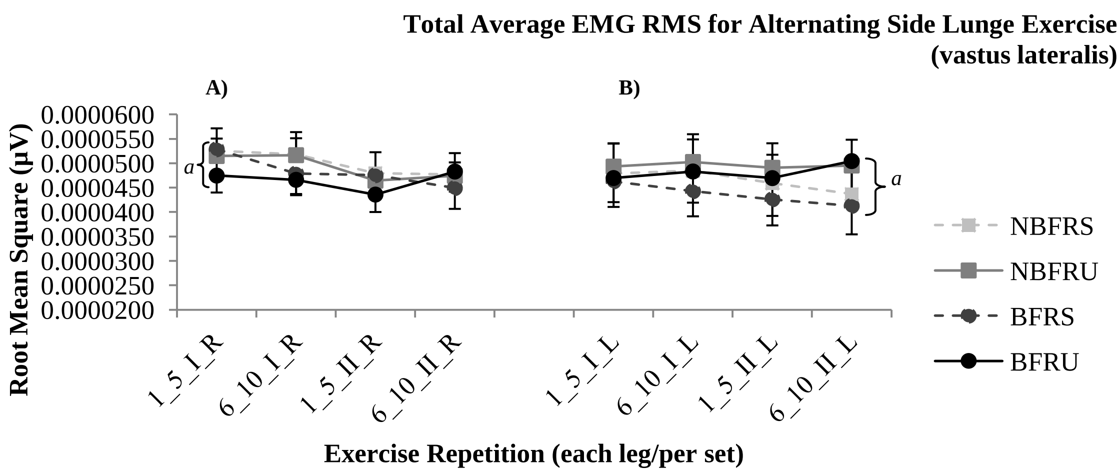
Figure 4. Average vastus lateralis EMG RMS during squat exercise.



[a] represents time difference within all conditions (p<0.05). Values reported as mean ± SE. N=16.

Figure 5 displays the average EMG RMS values for VL muscle during alternating side lunge exercise for both rounds (sets) per each 5 repetitions across the dynamic exercise repetitions with all 4 conditions (NBFRS, NBFRU, BFRS, BFRU) for (A) right leg and (B) left leg. A time (p=0.006) main effect for EMG RMS was detected by repeated measures ANOVA. There was a significant three-way interaction between surface*leg*gender (p=0.008), surface*time*gender (p=0.015), and blood flow*time*gender (p=0.040). There was a significant two-way interaction for surface*leg (p= 0.026) and surface*time (p<0.01) (Figure 5).

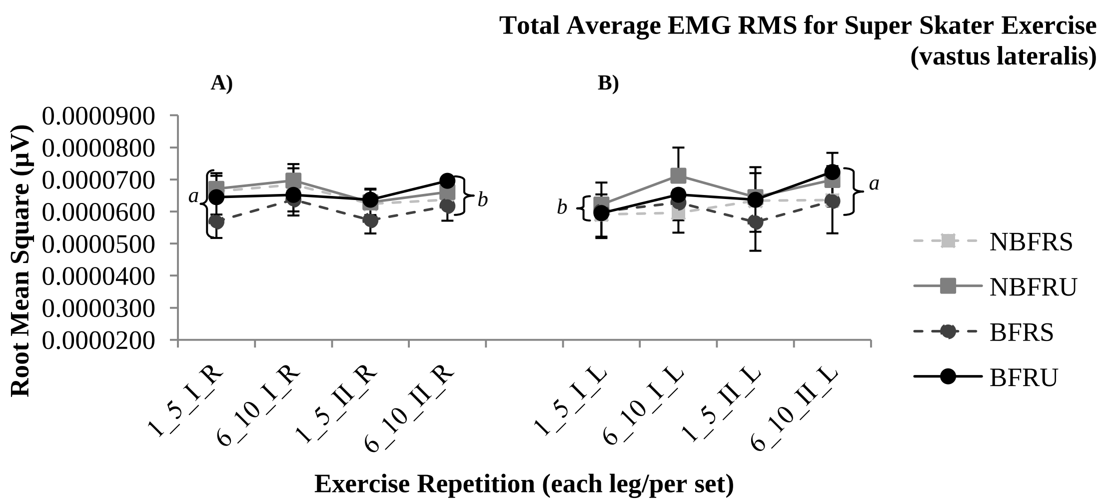
Figure 5. Average vastus lateralis EMG RMS during alternating side lunge exercise.



[a] represents time difference within all conditions (p<0.05). Values reported as mean ± SE. N=16.

Figure 6 displays the average EMG RMS values for VL muscle during super skater exercise for both rounds (sets) per each 5 repetitions across the dynamic exercise repetitions with all 4 conditions (NBFRS, NBFRU, BFRS, BFRU) for (A) right leg and (B) left leg. A surface (p=0.030) and time (p<0.01) main effects for EMG RMS were detected by repeated measures ANOVA. There was a significant three-way interaction between surface*blood flow*time (p=0.040). No significant two-way interaction was found (Figure 6).

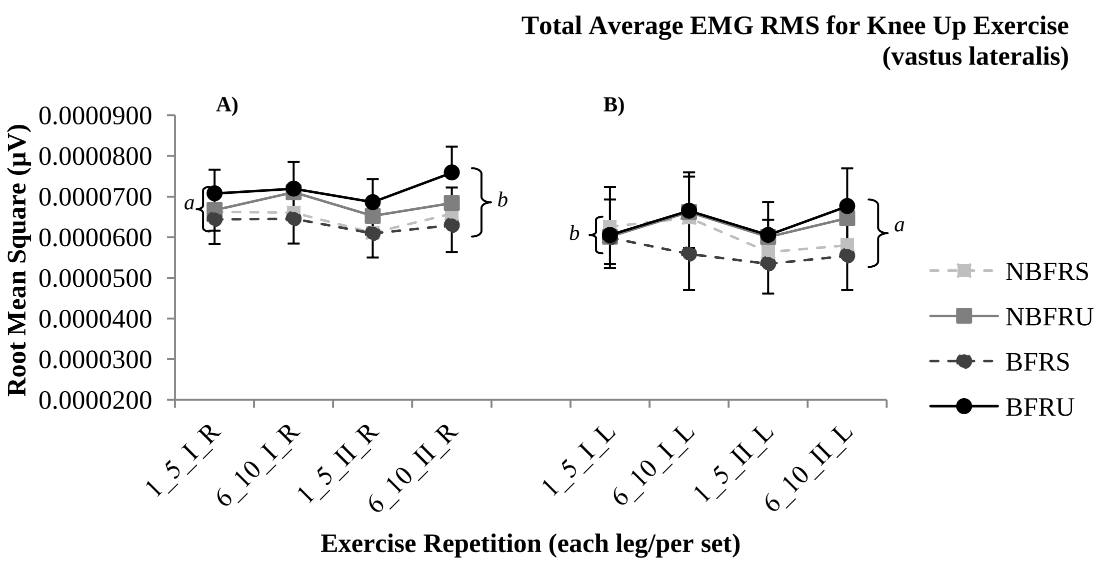
Figure 6. Average vastus lateralis EMG RMS during super skater exercise.



[a] represents time difference within all conditions (p<0.05); [b] represents surface difference within all conditions (p<0.05). Values reported as mean ± SE. N=16.

Figure 7 displays the average EMG RMS values for VL muscle during knee up exercise for both rounds (sets) per each 5 repetitions across the dynamic exercise repetitions with all 4 conditions (NBFRS, NBFRU, BFRS, BFRU) for (A) right leg and (B) left leg. A surface (p=0.018) and time (p<0.01) main effects for EMG RMS were detected by repeated measures ANOVA. There was a significant three-way interaction between blood flow*time*gender (p=0.002). One significant two-way interaction was found between surface*time (p=0.001) (Figure 7).

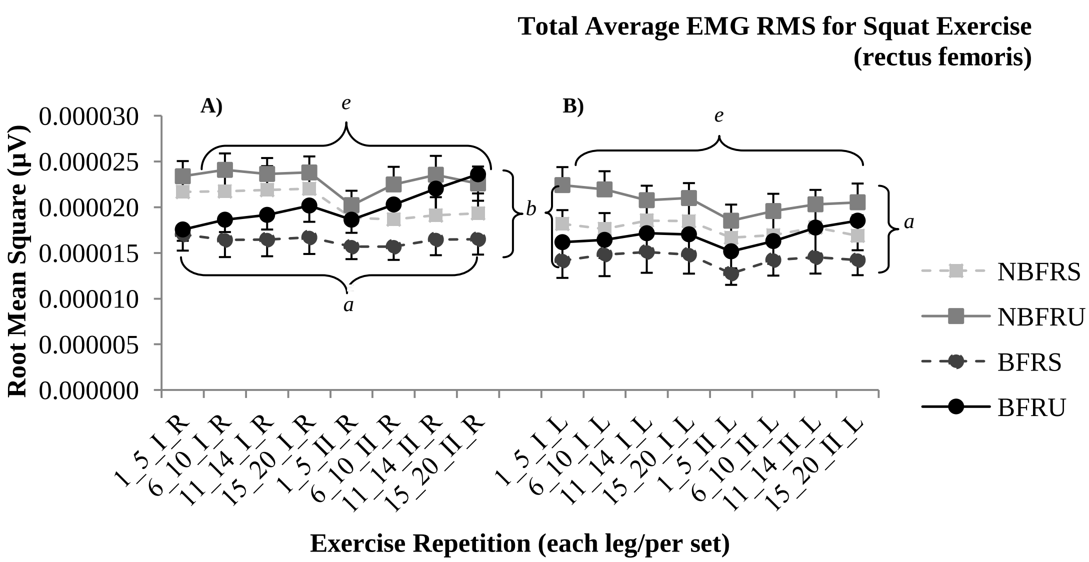
Figure 7. Average vastus lateralis EMG RMS during knee up exercise.



[a] represents time difference (p<0.05); [b] represents surface difference within all conditions (p<0.05). Values reported as mean ± SE. N=16.

Figure 8 displays the average EMG RMS values for RF muscle during squat exercise for both rounds (sets) per each 5 repetitions across the dynamic exercise repetitions with all 4 conditions (NBFRS, NBFRU, BFRS, BFRU) for (A) right leg and (B) left leg. A surface (p=0.048), leg (p<0.002) and time (p=0.001) main effect for EMG RMS was detected by repeated measures ANOVA. There was a significant three-way interaction between blood flow*leg*time (p=0.036). One significant two-way interaction was found between blood flow*time (p<0.01) (Figure 8).

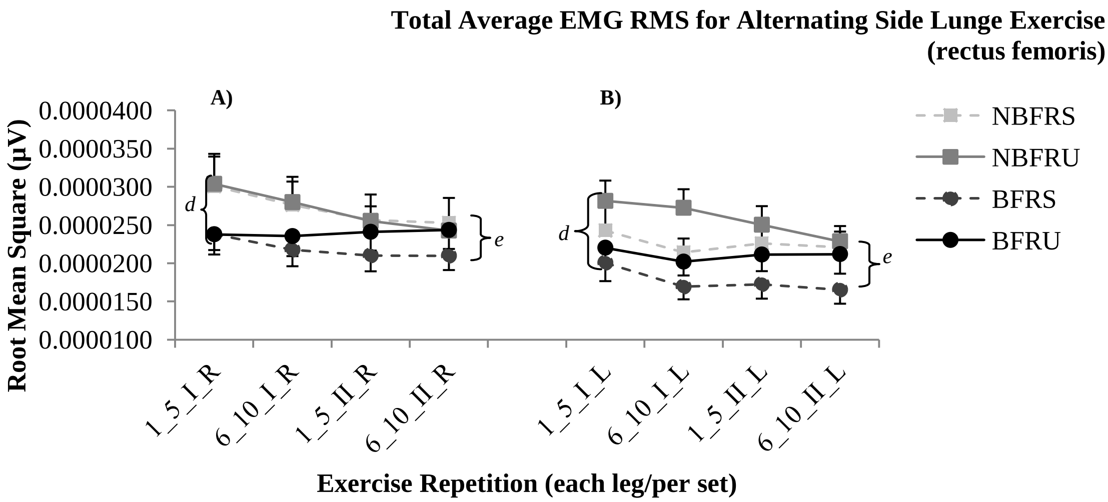
Figure 8. Average rectus femoris EMG RMS during squat exercise.



[a] represents time difference (p<0.05); [b] represents surface difference within all conditions (p<0.05); [e] represents leg differences within all conditions (p=0.001). Values reported as mean ± SE. N=16.

Figure 9 displays the average EMG RMS values for RF muscle during alternating side lunge exercise for both rounds (sets) per each 5 repetitions across the dynamic exercise repetitions with all 4 conditions (NBFRS, NBFRU, BFRS, BFRU) for (A) right leg and (B) left leg. A blood flow (p=0.018), leg (p=0.021) and time (p=0.007) main effect for EMG RMS was detected by repeated measures ANOVA. No significant three-way interaction was observed. One significant two-way interaction was observed between leg*gender (p=0.038) (Figure 9).

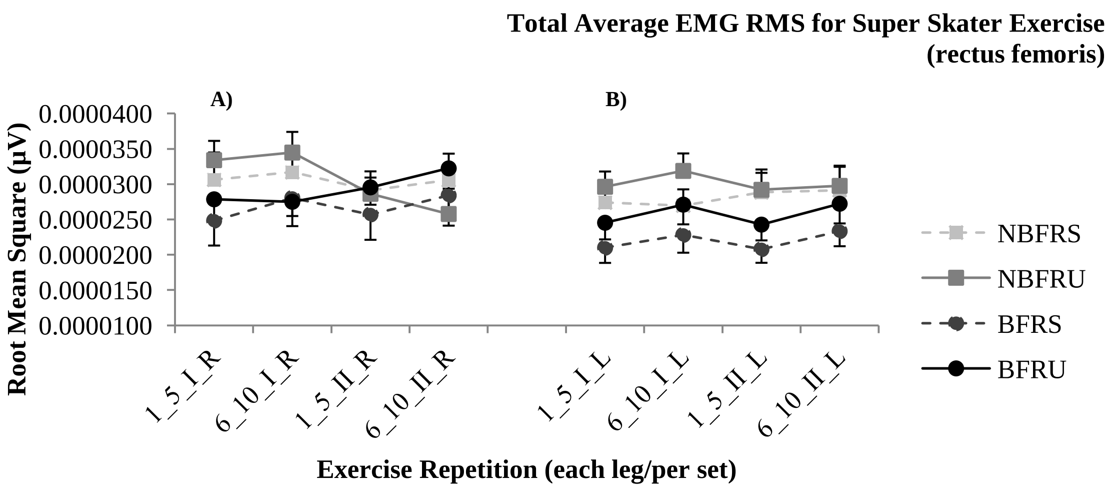
Figure 9. Average rectus femoris EMG RMS during alternating side lunge exercise.



[d] represents blood flow restriction difference (p<0.05); [e] significant leg difference within all conditions (p<0.05). Values reported as mean ± SE. N=16.

Figure 10 displays the average EMG RMS values for RF muscle during super skater exercise for both rounds (sets) per each 5 repetitions across the dynamic exercise repetitions with all 4 conditions (NBFRS, NBFRU, BFRS, BFRU) for (A) right leg and (B) left leg. Three significant three-way interactions were found between surface*time*gender (p=0.05), surface*blood flow*time (p=0.014), and blood flow*leg*time (p=0.031). One significant two-way interaction was found between blood flow*time (p=0.032) (Figure 10).

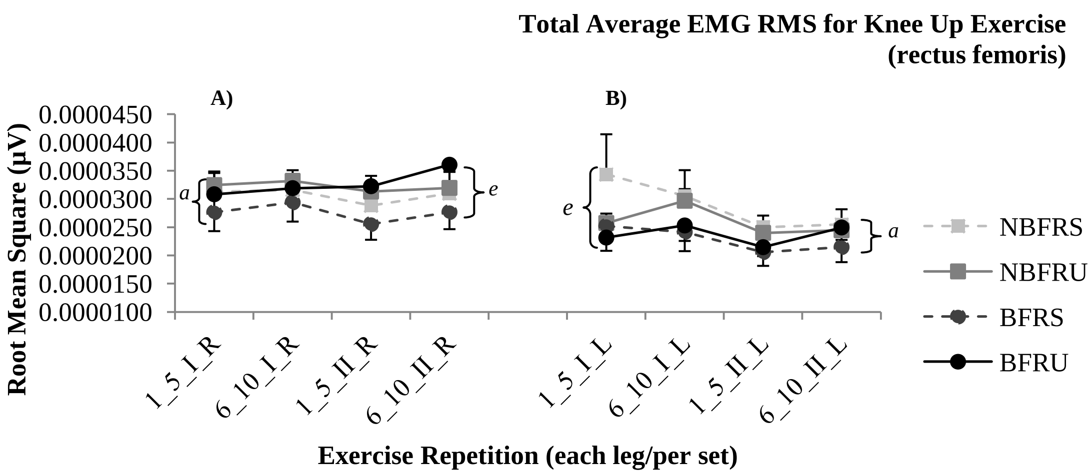
Figure 10. Average rectus femoris EMG RMS during super skater exercise.



Significant differences were shown in surface*time*gender (p=0.05), blood flow*time (p=0.032), surface*blood flow*time (p=0.014), blood flow*leg*time (p=0.031). Values reported as mean ± SE. N=16.

Figure 11 displays the average EMG RMS values for RF muscle during knee up exercise for both rounds (sets) per each 5 repetitions across the dynamic exercise repetitions with all 4 conditions (NBFRS, NBFRU, BFRS, BFRU) for (A) right leg and (B) left leg. A leg (p=0.001) and time (p=0.002) main effect for EMG RMS was detected by repeated measures ANOVA. No significant three-way interaction was shown. One significant two-way interaction was shown between surface*time (p=0.023) (Figure 11).

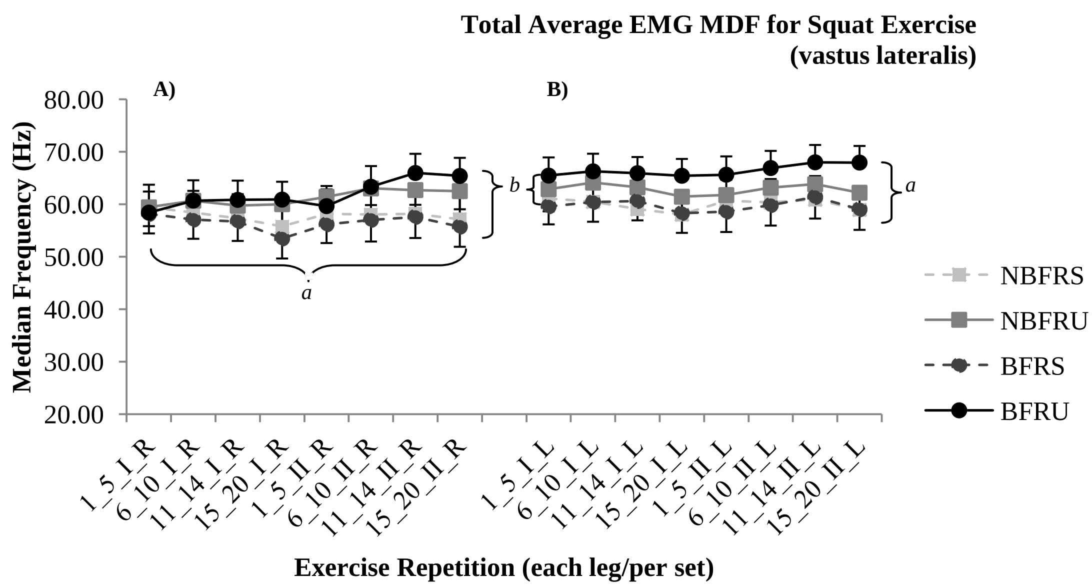
Figure 11. Average rectus femoris EMG RMS during knee up exercise.



[a] represents time difference (*p*<0.05); [e] represents leg difference within all conditions (*p*<0.05). Values reported as mean ± SE. N=16.

Figure 12 displays the average EMG median frequency (MDF) values for VL muscle during squat exercise for both rounds (sets) per each 5 repetitions across the dynamic exercise repetitions with all 4 conditions (NBFRS, NBFRU, BFRS, BFRU) for (A) right leg and (B) left leg. A surface (p=0.029) and time (p<0.01) main effect for EMG MDF was detected by repeated measures ANOVA. One significant three-way interaction was shown between surface*leg*time (p=0.001). One significant two-way interaction was observed between surface*time (p=0.009) (Figure 12).

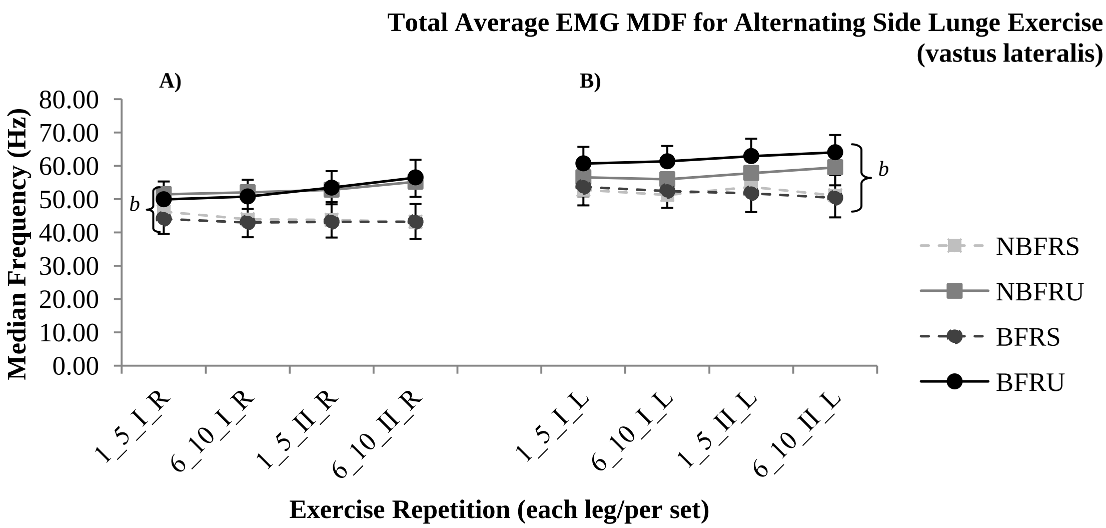
Figure 12. Average vastus lateralis EMG MDF during squat exercise.



[a] represents time difference (p<0.05); [b] represents surface difference within all conditions (p<0.05). Values reported as mean ± SE. N=16.

Figure 13 displays the average EMG MDF values for VL muscle during alternating side lunge exercise for both rounds (sets) per each 5 repetitions across the dynamic exercise repetitions with all 4 conditions (NBFRS, NBFRU, BFRS, BFRU) for (A) right leg and (B) left leg. A surface ($p<0.01$) main effect for EMG MDF was detected by repeated measures ANOVA. One significant three-way interaction was found between blood flow*leg*time ($p=0.032$). One significant two-way interaction was found between surface*time ($p<0.01$) (Figure 13).

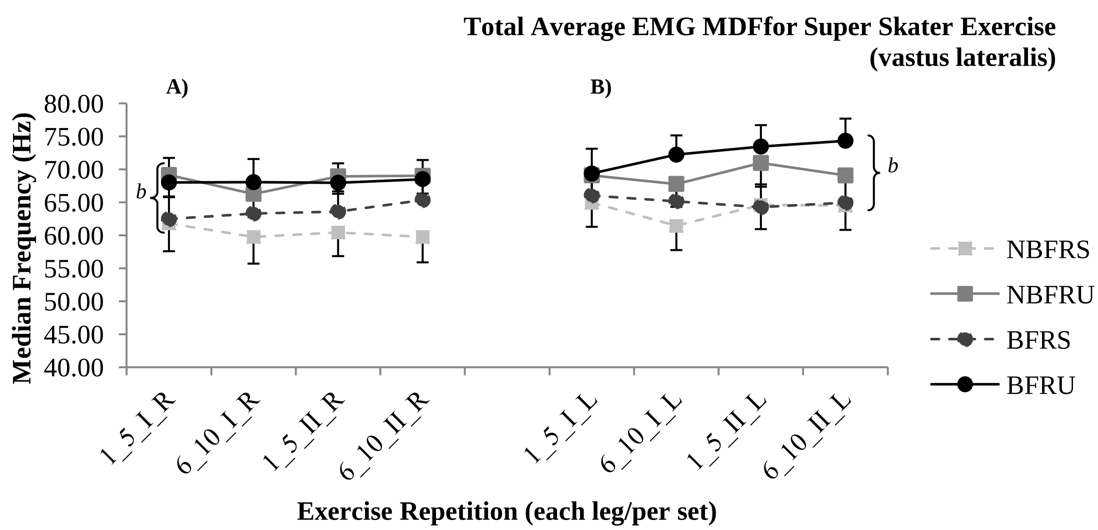
Figure 13. Average vastus lateralis EMG MDF during alternating side lunge exercise.



[b] represents surface difference ($p<0.05$). Values reported as mean ± SE. N=16.

Figure 14 displays the average EMG MDF values for VL muscle during super skater exercise for both rounds (sets) per each 5 repetitions across the dynamic exercise repetitions with all 4 conditions (NBFRS, NBFRU, BFRS, BFRU) for (A) right leg and (B) left leg. A surface ($p<0.01$) main effect for EMG MDF was detected by repeated measures ANOVA. One significant four-way interaction was shown between surface*blood flow*leg*time ($p=0.040$). No significant three-way interaction was shown. One significant two-way interaction was shown between blood flow*time ($p=0.012$) (Figure 14).

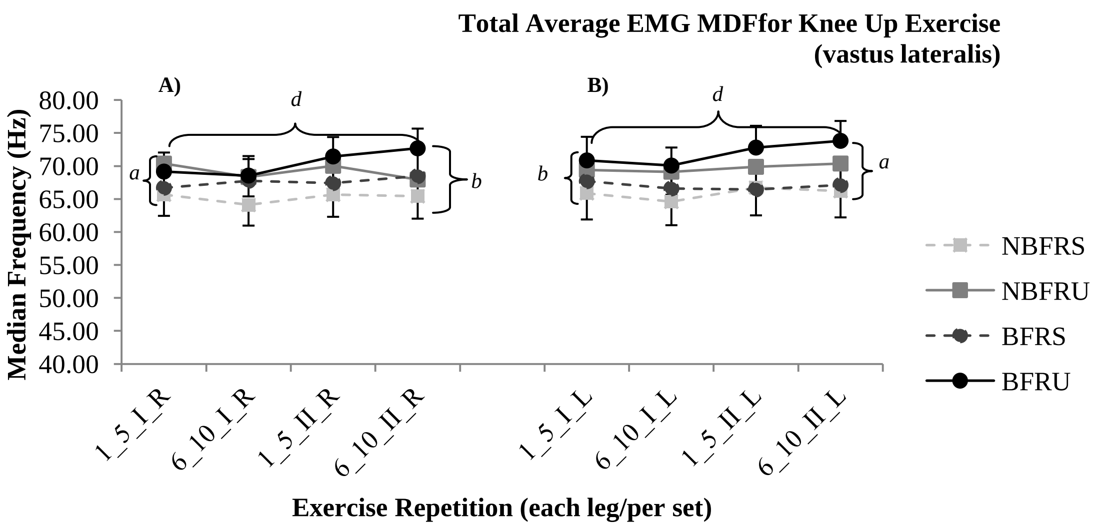
Figure 14. Average vastus lateralis EMG MDF during super skater exercise.



[b] represents surface difference ($p<0.05$). Values reported as mean ± SE. N=16.

Figure 15 displays the average EMG MDF values for VL muscle during super skater exercise for both rounds (sets) per each 5 repetitions across the dynamic exercise repetitions with all 4 conditions (NBFRS, NBFRU, BFRS, BFRU) for (A) right leg and (B) left leg. A surface (p=0.003), blood flow (p=0.036) and time (p=0.017) main effect for EMG MDF was detected by repeated measures ANOVA. No significant three-way interaction was shown. No significant two-way interaction was observed (Figure 15).

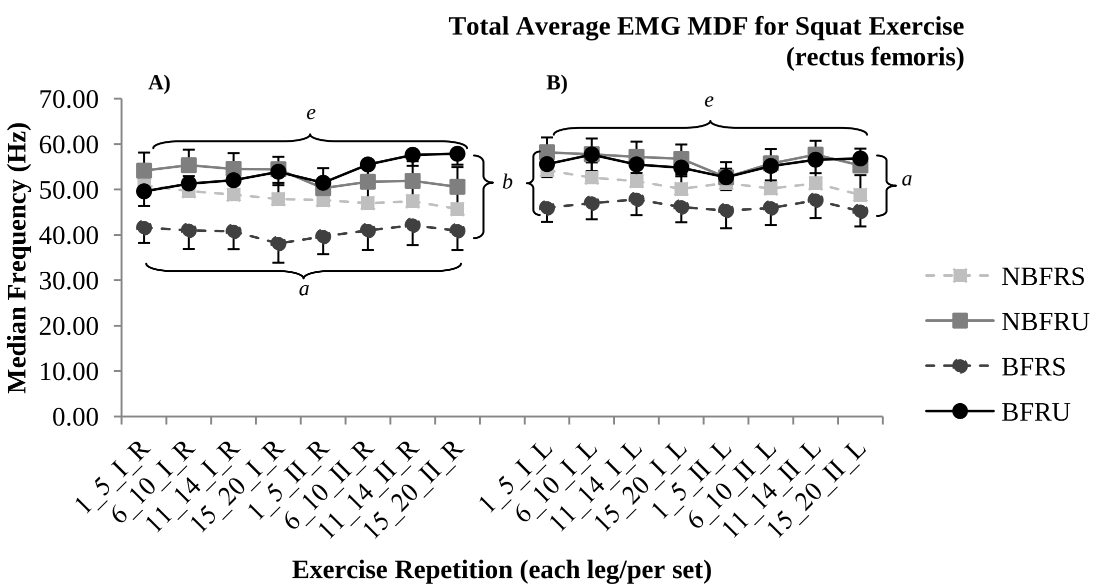
Figure 15. Average vastus lateralis EMG MDF during knee up exercise.



[a] represents time difference (p<0.05); [b] represents surface difference within all conditions (p<0.05); [d] represents blood flow difference within all conditions (p<0.05). Values reported as mean ± SE. N=16.

Figure 16 displays the average EMG MDF values for RF muscle during squat exercise for both rounds (sets) per each 5 repetitions across the dynamic exercise repetitions with all 4 conditions (NBFRS, NBFRU, BFRS, BFRU) for (A) right leg and (B) left leg. A surface (p=0.010), leg (p=0.033) and time (p=0.047) main effect for EMG MDF was detected by repeated measures ANOVA. One significant three-way interaction was found between blood flow*leg*time (p=0.019). Three significant two-way interactions were found between time*gender (p=0.005), surface*blood flow (p=0.080) and blood flow*leg*time (p=0.019) (Figure 16).

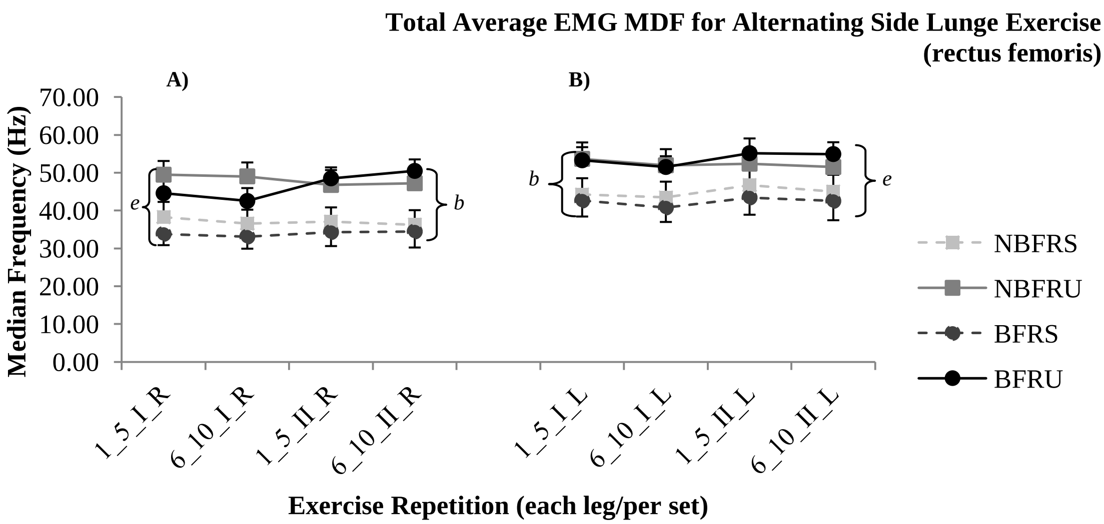
Figure 16. Average rectus femoris EMG MDF during squat exercise.



[a] represents time difference (p<0.05); [b] represents surface difference within all conditions (p<0.05); [e] represents leg difference within all conditions (p<0.05). Values reported as mean ± SE. N=16.

Figure 17 displays the average EMG MDF values for RF muscle during alternating side lunge exercise for both rounds (sets) per each 5 repetitions across the dynamic exercise repetitions with all 4 conditions (NBFRS, NBFRU, BFRS, BFRU) for (A) right leg and (B) left leg. A surface (p<0.01) and leg (p=0.003) main effect for EMG MDF was detected by repeated measures ANOVA. No significant three-way interaction was found. Two significant two-way interaction was found between surface*gender (p=0.034) and blood flow*time (p=0.012) (Figure 17).

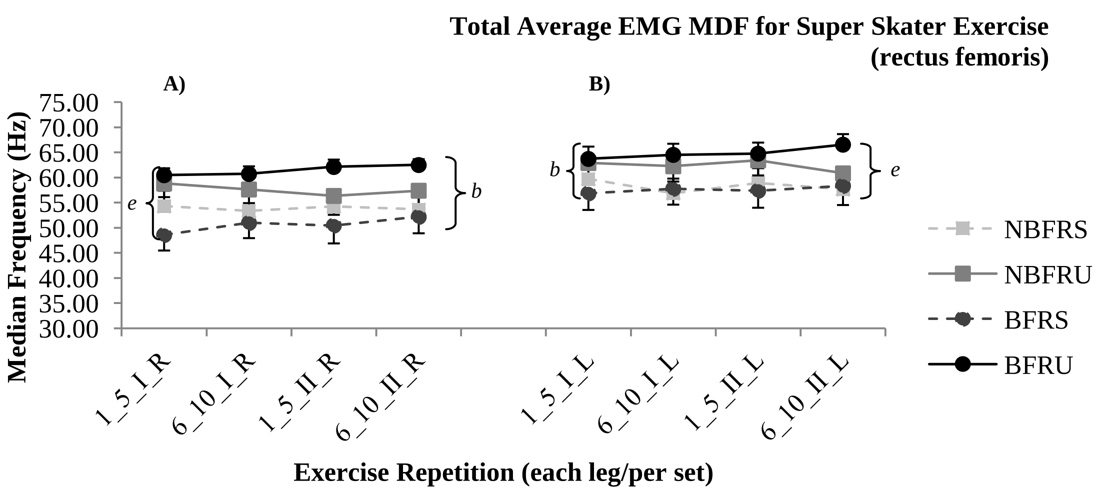
Figure 17. Average rectus femoris EMG MDF during alternating side lunge exercise.



[b] represents surface difference (p<0.05); [e] represents leg difference within all conditions (p<0.05). Values reported as mean ± SE. N=16.

Figure 18 displays the average EMG MDF values for RF muscle during super skater exercise for both rounds (sets) per each 5 repetitions across the dynamic exercise repetitions with all 4 conditions (NBFRS, NBFRU, BFRS, BFRU) for (A) right leg and (B) left leg. A surface (p=0.001) and leg (p=0.011) main effect for EMG MDF was detected by repeated measures ANOVA. No significant three-way interaction was found. Two significant two-way interaction was found between surface*blood flow (p=0.032) and blood flow*time (p=0.002) (Figure 18).

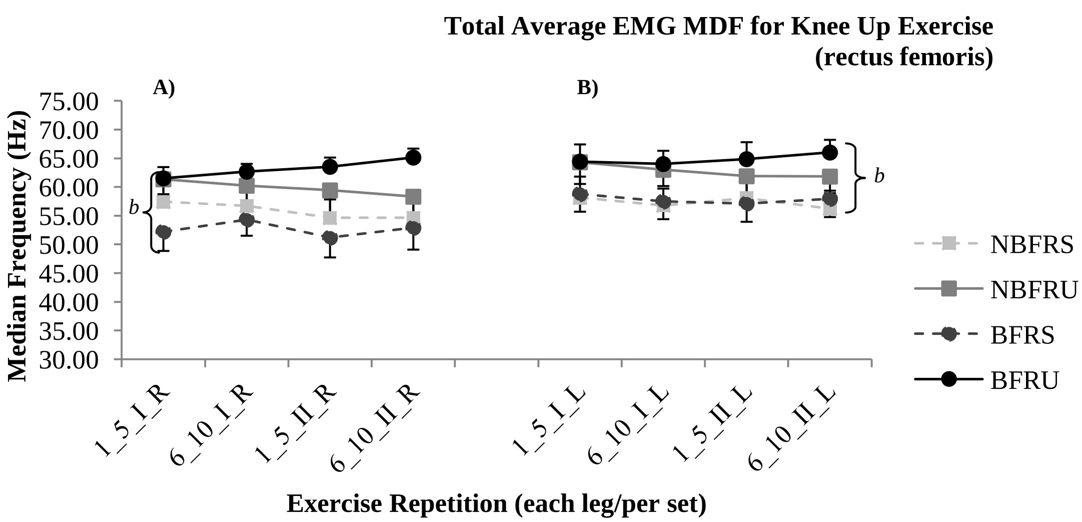
Figure 18. Average rectus femoris EMG MDF during super skater exercise.



[b] represents surface difference ($p<0.05$); [e] represents leg difference within all conditions ($p<0.05$). Values reported as mean ± SE. N=16.

Figure 19 displays the average normalized EMG MDF values for RF muscle during knee up exercise for both rounds (sets) per each 5 repetitions across the dynamic exercise repetitions with all 4 conditions (NBFRS, NBFRU, BFRS, BFRU) for (A) right leg and (B) left leg. A surface (p=0.001) main effect for EMG MDF was detected by repeated measures ANOVA. One significant four-way interaction was found between surface*blood flow*leg*gender (p=0.042). One significant three-way interaction was found between surface*blood flow*leg (p=0.032). One significant two-way interaction was found between surface*blood flow (p=0.046) (Figure 19).

Figure 19. Average rectus femoris EMG MDF during knee up exercise.



b represents a significant surface difference ($p<0.05$). Values reported as mean ± SE. N=16.

DISCUSSION

Cardiovascular Response

The environmental conditions during exercise as well as the type, intensity and duration of the exercise are responsible for the changes and increases in heart rate during exercise (Powers & Howley, 2009). The unstable surface resulted in a significantly higher heart rate compared to the stable surface. This may be caused by the greater effort made to maintain balance on an unstable surface. It is essential to force the body to adapt to new stimuli according to the Selye's adaptation curve (Selye, 1956; Sands, Wurth, & Hewit, 2012). It can be speculated that the unstable surface had a higher heart rate compared to the stable surface due to the greater challenge of a new training environment. An advantage of the unstable training environment would be based on the importance of neuromuscular adaptations with increases in strength (Behm & Anderson, 2006).

Although the differences were not significant in the present study, the female subjects had a higher HR compared to the male subjects. A research study has suggested that HR can be affected by gender (Perini, Milesi, Fisher, Pendergast, & Veicsteinas, 2000). Huikiri et al. (1996) found that baroreflex sensitivity is less in middle aged men compared to middle aged women. This may result in the increase of parasympathetic and/or a decrease in sympathetic HR modulation that may occur in female than in males (Ryan, Goldberger, Pincus, Mietus, & Lipsitz, 1994; Huikiri, et al., 1996). Female participants generally have a smaller heart compared to male participants causing a higher heart rate during exercise due to the higher frequency of the heart contractions.

Ryan et al. (1994) also found a higher heart rate was higher in women compared to men. The females in the current study resulted in higher HR values compared to the male subjects.

Significant increases in HR are generally evident during BFR exercise at a constant workload (Abe et al. 2010; Abe et al. 2005; Ozaki et al. 2011; Takano et al. 2005). Even though the current study found no significant differences between BFR conditions and NBFR conditions, the non-BFR conditions had a lower heart rate compared to the BFR conditions. Abe et al. (2005) studied the effects of BFR walking in young, healthy males. Subject underwent training six days a week, twice a day, for three weeks. Each testing session consisted of five sets of two minutes walking bouts with a one minutes rest between bouts at a speed of 50 m/ minutes. Heart rate was found to be significantly higher in the BFR group than the non-BFR group. Similarly, an 8 week BFR study, young males performed cycling exercise at 40% VO_2max for 15 minutes compared to the non-BFR group, which exercised at the same intensity for 45minutes (Abe, et al., 2010). BFR subjects performed 40% of VO2 max for 15 minutes. The cuff pressure was selected between 160-210 mmHg. BFR cycling exercise resulted in a higher HR response (Abe, et al., 2010). Ozaki et al. (2011) found BFR exercise to increase HR 23% greater than non-BFR when performing upright cycling exercise at 20%, 40% and 60% VO_2max in ten young healthy males. Subjects cuff pressures varied between 160-200 mmHg. The present findings failed to show a significant difference between NBFR and BFR conditions as the previous BFR studies did. This may be due to the low intensity of the exercises since participants performed body weight exercises and no weight was added. Total restrictive pressure used may also be another possible factor of why no significant differences were found in the present study. This may be due to the method used to define TRP in the current study compared to the previous studies. Previous studies determined TRP using formula that utilizes arm SBP. However, the present study used a different approach by using the leg circumference to determine the TRP.

Restrictive pressures applied by the BFR cuff may affect other variables such as the level of arterial blood inflow and venous return resulting in variation in BFR-induced HR response. Abe et al. (2010) also reported the effects and importance of the unique combination of arterial blood inflow and venous blood volume pooling during BFR conditions. The authors speculated that the increased heart rate could be due to the decrease in stroke volume in order to maintain cardiac output. Stroke volume is also affected due to the decrement in venous return in the blood flow restricted limbs (Karabulut, Mccarron, Abe, Sato, & Bemben, 2011; Iida et al., 2007; Yasuda et al., 2010). Although there was not a significant difference in the blood flow and non-blood flow conditions, the results of the present study found higher values in HR during BFR conditions. Heart rate responses are generally shown to increase during blood flow restricted conditions compared to the non-blood flow restricted conditions.

Blood Pressure

Blood pressure can be increased by increasing blood volume, heart rate, blood viscosity, stroke volume and/or an increase in peripheral resistance (Powers & Howley, 2009). Although differences in blood pressure (BP) responses between conditions did not reach significance level in the present study, SBP values observed were higher in the BFR conditions compared to the NBFR conditions. Sakamaki et al. (2008) states that moderate to high-intensity resistance training exercise increases both systolic blood pressure (SBP) and diastolic blood pressure (DBP) as well as mean arterial pressure (MAP). However the BFR exercise induced increase in BP may also involve an increase in cardiac output and elevated total peripheral resistance (Sakamaki, Fujita, Sato, Bemben, & Abe, 2008). An increase in cardiac output means there is an increase in HR and/or stroke volume, both of which can cause an increase in blood pressure values.

It has been well documented that moderate to high-intensity resistance exercise markedly increases SBP, as well as MAP. MacDougall et al. (1985), reported extreme pressure increases (SBP, 250-320 mmHg) in young bodybuilders when these individuals were exposed to 95% of 1 RM double-leg seated leg press exercises to failure. Similarly, Fleck et al. (1987), found increases in SBP (190-195 mmHg) and DBP (140-155 mmHg) during one leg knee extension with intensity between 70 and 90% of 1RM in young males. Generally, an increase is found in blood pressure during exercise and an even higher response is observed when intensity increases (Fleck et al. 1987; MacDougall et al.. 1985). Takano et al. (2005) performed a study with 11 untrained men, who performed KAATSU training at 20% of 1-RM. Subjects performed 30 repetitions and rested for 20 seconds which then they performed 3 more sets until exhaustion. Takano et al. (2005) found that the maximal HR and blood pressure was higher in KAATSU conditions compared to the non-KAATSU condition. Overall, the current study failed to parallel with previous BFR studies. No significant difference was found, however a higher blood pressure was observed in the BFR conditions compared to the NBFR conditions. This may be primarily due to the low intensity of the exercises performed in the current study.

Subjects performed exercises with no additional weight therefore they performed low intensity exercises.

Leg Difference

Most of the subjects were reported to be right leg dominant (N=13, 81%) and a few were left leg dominant (N=3, 19%). When comparing legs, it is important to consider the roles played by each leg during different tasks such as mobility and stability. One leg, usually the dominant leg, plays the role during the mobility tasks such as kicking a soccer ball or football whereas the other leg, usually the non-dominant leg, plays the equally important role of stability and postural control (Velotta, Weyer, Ramirez, Winstead, & Bahamonde, 2011).This present study reported leg differences between the left and right leg. The VL and the RF EMG RMS measures on the right leg were higher compared to the left leg. The VL and the RF EMG MDF measures on the left leg were higher compared to the right leg. For RF muscle, both EMG measures, RMS and MDF, were generally significant when comparing leg differences. It may be speculated that since majority of the subjects are right-leg dominant, they may have a higher dependence on their left leg in order to maintain balance. Additional information about RMS and MDF response will be discussed in greater detail during the muscle function section.

Subjects in the study by Kibele et al. (2009) performed a single legged hop test to provide any indication of right and left power as well as any power imbalances. Subjects were separated into unstable and stable resistance training programs that both performed single-leg hops with each leg for a distance of 20 m. No significant differences were recorded in the study however the unstable training group resulted in superior values for right leg hop test. This may be a result due to the greater equilibrium stress placed on the right leg which may also display a greater training adaptation for balance with the unstable resistance training group (Kibele & Behm, 2009). The dominant right leg is used to kick, punt or perform the activity while the non-dominant leg, in this case the left leg, must maintain balance. Similarly, Velotta et al. (2011) found that the leg dominance seems to change depending on the exercise or task the subject is required to perform. In this study, 22 subjects (9 males and 13 females) were asked to perform four commonly used manipulative tests in order to determine the leg dominance. Subjects were also asked to perform two balance tests and were given the option to select the leg they preferred to perform the exercise with. The left leg was preferred for the balance testing in over 50% of the subjects although for mobility testing most of the subjects preferred their dominant right leg. This may be why the left leg may not have experienced as great a balanced training adaptation as the right leg due to that it is given the greater responsibility for balance when performing unilateral leg actions (Kibele & Behm, 2009).

Ratings of Perceived Exertion

Loenneke et al. (2012) described the rating of perceived exertion (RPE) to be based off of the subjects strain and fatigue in the muscles. The present study detected significant main effects for BFR and time highlighting the importance of blood flow or venous return of the working muscle and the time for how the participants feel about exertion. The non-BFR exercises were less tiring compared to the BFR measure. The findings from the present study parallels with the results from Ozaki et al. (2011) where subjects were split into two different groups either the BFR walk training group or a walk training group without BFR. During all training sessions, RPE measures were recorded every 5 minutes. They found that their BFR condition also resulted in significantly higher RPE values for the BFR walk group compared to the control group. In a study conducted by Sakamaki, et al. (2008), seven active subjects (64-78years) performed walking test without (control group) and with BFR (BFR group). No significant differences in RPE were found between conditions however; this study also found that the rating of perceived exertion increases during BFR. The findings from Sakamaki et al. (2008) also coincides with the study performed by Loenneke et al. (2012) that reported no significant differences between control and BFR conditions however; the conditions receiving BFR reported higher RPE values. Subjects in the study were randomized into two different experiment groups, A and B. In experiment A, subjects performed unilateral knee extensions at 30% of their one repetition maximum (1RM) with moderate BFR to one leg and exercised the other leg without restriction. In experiment B, participants rested for 4 minutes with BFR applied to one leg and rested for 4 minutes without any treatment on the other leg. RPE was measured before and after each set and resulted in a consistently higher score for the exercise with BFR condition (Loenneke, Thiebaud, Fahs, Rossow, Abe, & Bemben, 2012). No studies observed gender differences for RPE therefore no findings are available to compare and discuss the gender differences found in the current study. However the results of the current study were not significant, female subjects recorded a lower RPE average compared to males. Surface differences in the current study were also not significant however they showed that the stable surface recorded a lower RPE measure compared to the unstable surface. Unstable surfaces affect RPE measures due to the higher demand the unstable surfaces requires. Since muscles perform greater balancing function on unstable surfaces, the muscle activation is high (Anderson & Behm, 2005). This maybe the reason for the higher RPE value found on an unstable surface for the current study.

Muscle Function

The results of the current study indicate that neuromuscular activity of the VL and RF was generally not significantly influenced by BFR. The present study indicates the RF and VL RMS signals were generally higher in the unstable surface compared to the stable surface sessions. It may be speculated that the unstable surface placed more stress on the muscles to adapt to the environment (Behm & Anderson, 2006) causing a greater neuromuscular activation. Although no significant difference was recorded, a higher RMS value in the non-BFR (NBFR) condition was recorded compared to the BFR condition (BFR) for RF and VL. This may be due to the higher number of muscle fibers recruited from both type I and type II muscle fibers. As mentioned in James et al. (2013), the level of activation and adaptation can be altered due to several factors such as the amount of blood flow to active muscles and the number of motor units activated (James & Karabulut, 2013). Changes in the blood flow to the skeletal muscle alter the level of supply of substrates and the removal of metabolites; therefore it will also affect the level of activation and recruitment of muscle fibers needed to perform exercises (James & Karabulut, 2013). Generally the type I muscle fibers are used when performing a low intensity exercise and are also used with type II fibers when performing high intensity exercises. However, by restricting the blood flow to the active muscles, the pattern and number of skeletal muscle fiber recruitment during exercise may be affected as well as the amount of neuromuscular activation and adaptation (James & Karabulut, 2013). BFR has shown to stimulate changes in neuromuscular activity and this may be a result of oxygen deficiency causing a shift from slow oxidative fibers to fast oxidative glycolytic fibers (James & Karabulut, 2013). Generally, NBFR conditions reported a higher RMS value due to the higher number of muscle fibers used compared to the lesser number used in BFR conditions. The leg difference for RMS was reported as generally significantly higher muscle fiber recruitment in the right leg compared to the left leg for RF and VL. Based on the results, it may be speculated that for the current study, the non-dominant leg, left leg, is used more for balancing than the dominant leg, right leg (Kibele et al. 2009; Velotta et al. 2011). The connection between the right leg, which is used more for gross movement, muscle fibers and the nervous system may not be as developed as it is for to the left leg (Velotta, Weyer, Ramirez, Winstead, & Bahamonde, 2011). For stabilizing movements, the right leg may not be accustomed to the balance stressor therefore the right leg is shown in the study to recruit and use more muscle fibers compared to the left leg causing higher RMS values.

The present study indicates the RF and VL MDF (MDF) signals were generally significantly higher in the unstable surface compared to the stable surface sessions. The results are similar to the results found by Anderson et al. (2005), which found the trunk muscles to be more active during the unstable surface. It can be speculated that the unstable surface constantly forces more muscles to be used to adapt causing the increase in firing frequency. Although no significant difference was recorded, a higher MDF value in the BFR condition was recorded compared to the non-BFR condition (NBFR) for RF and VL. Katayama et al. (2010) conducted a study supporting that higher neuromuscular activation was induced by hypoxia. The changes in muscle fiber activation from type I to type II fibers and increased motor unit recruitment occurred due to the hypoxic conditions. It can be speculated that due to the high dependence of oxidative phosphorylation, slow-twitch muscle fibers may not contribute to the force production during the restricted blood flow exercises (Karabulut & Perez, 2013; Katayama, Yoshitake, Watanabe, Akima, & Ishida, 2010). This is why it can be contemplated that a higher muscle firing frequency was found in the blood flow restricted condition due to the fewer number of muscle fibers recruited. These fibers needed to be stimulated more often to meet demands of the exercise.

CHAPTER V

CONCLUSION

The purpose of this study was to test several measures (heart rate, blood pressure, muscle unit activation and rate of perceived exertion) when performing various lower body hemodynamic circuit training exercises on stable and unstable surface with and without vascular restriction. The following research questions were addressed and conclusions were drawn based on the findings of the current study: 1) Which measure, without BFR or with BFR on stable or unstable surface, will cause a significant difference in heart rate, blood pressure, and rate of perceived exertion? 2) Will the unstable surface have significant differences on changes in motor unit activation and motor unit action potential firing frequency in response to exercises performed on stable and unstable surface with and without BFR? 3) Will the male participants results be significantly different compared to the female participants?

Research hypothesis 1. BFR training on unstable surface will cause significantly higher heart rate and blood pressure as well as a greater rate of perceived exertion compared to other conditions.

No, the present study does not support this hypothesis. Although no significant differences were observed, a higher heart rate, blood pressure and rate of perceived exertion was recorded for the (BFRU) condition.

Research hypothesis 2. With an increase in instability, muscle activation will increase. Instability with BFR on an unstable surface condition will have a greater muscle activation increase compared to the other conditions.

No, the present study does not support this hypothesis. Muscle activation did increase with an increase in instability; however, instability with BFR did not cause the greatest muscle activation.

Research hypothesis 3. Male participants will be significantly different compared to female participants.

No, the present study does not support this hypothesis. No significant differences were found when comparing the female participants to the male participants.

Implications of the Study

Even though no significant changes in several physiological responses was observed in the present study, necessary adjustments in the exercise protocol such as changing the number of exercises and/or repetitions and/or circuits may result in changes in the level of responses in the physiological parameters tested. Therefore, circuit and BFR training may provide benefits for cardiorespiratory system, skeletal muscle strength and muscle size. Instability training adds a greater emphasis on trunk muscle activation. This form of training may also provide a new alternative way of resistance training with a greater emphasis on trunk activation and balance with instability training. Generally a high volume approach may be necessary to cause fatigue in the preferentially recruited type I fibers and thus enable the recruitment of higher threshold type II fibers. However, with BFR, a high volume may not be necessary to stimulate the type II fibers.

Suggestions for Future Research

Further research is still necessary using BFR with instability training on: 1) fatigue effect pre and post exercise 2) muscle hypertrophy and strength gain from anaerobic physical activity 3) possible effects from chronic use 4) muscle and caloric expenditure 5) lower body static exercises 6) higher cuff pressures.

The findings of the present study failed to show significant differences for BFR affecting heart rate, blood pressure, rate of perceived exertion and EMG activity (muscle fiber recruitment and firing frequency). Future research may use static exercises or a higher cuff pressure to show a possible increase in these measures while performing exercises on an unstable surface. The benefits for possible specific sports performance could be another area to be explored.

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APPENDICES

Appendix A. Recruitment Flyer

Appendix B. IRB Approval Letter

Appendix C. Informed Consent

Appendix D. PAR-Q

Appendix E. Health Status Questionnaire

Appendix F. Data Collection Sheets

Appendix A.

Recruitment Flyer

Appendix B.

IRB Approval Letter

Research Integrity and Compliance
The University of Texas at Brownsville

Matthew Johnson, Ph.D.
IRB Chair

March 26, 2013

Dr. Murat Karabulut
Health and Human Performance
The University of Texas at Brownsville
80 Fort Brown,
Brownsville, Texas 78520

Approval Type:
☐ Full Board Review
☒ Designated Member Review
☐ Continuing Review
☐ Change request/Modification/Amendment
☐ Exempt Category
☒ Expedited Category **4**

RE: IRB-HS Approval

Study Title: "Hemodynamic and Neuromuscular Responses to Exercises Performed on Stable and Unstable Surface with and without Blood Flow Restriction"

Approval Period:
Start Date: March 26, 2013
End Date: March 25, 2014

Protocol #: 2013-030-IRB

Dear Dr. Karabulut,

In accordance with Federal Regulations for review of research protocols, the Institutional Review Board – Human Subjects of The University of Texas at Brownsville has reviewed your study as requested.

The IRB-HS grants its approval for this project contingent on compliance with the following items. <u>You may make as many copies of the stamped consent form as are necessary for your activity. All consent forms MUST bear the UTB IRB stamp indicating approval.</u>

Responsibilities of the Principal Investigator also include:

- **Inform the IRB-HS in writing immediately of any emergent problems or proposed changes.**
- **Do not proceed with the research until any problems have been resolved and the IRB-HS have reviewed and approved any changes.**
- **Report any significant findings that become known in the course of the research that might affect the willingness of the subjects to take part.**
- **Protect the confidentiality of all personally identifiable information collected.**
- **Submit for review and approval by the IRB-HS all modifications to the protocol or consent form(s) prior to implementation of any change(s).**
- **Submit an activity/progress report regarding research activities to the IRB-HS on no less than an annual basis or as directed by the IRB-HS through the <u>Continuing Review Form.</u>**
- **Notify the IRB-HS when study has been completed through submission of a <u>Project Completion Report</u>.**

Should you have any questions or need any further information concerning this document please feel free to contact me at (956) 882-8888 or via email at Matthew.Johnson@utb.edu .

Sincerely yours,

Matthew Johnson, Ph.D.

Matthew Johnson, Ph.D.
IRB – Chair

80 Fort Brown • BRHP 2.210 • Brownsville, Texas 78520 • 956-882-7731 • research.compliance@utb.edu

Appendix C.

IRB Approval Letter

Subject Form

University of Texas at Brownsville/TSC
Institutional Review Board
Informed Consent to Participate in a Research Study

Project Title: Hemodynamic and Neuromuscular Responses to Exercises Performed on Stable and Unstable Surface with and Without Blood Flow Restriction
Principal Investigator: Dr. Murat Karabulut, Agnelia Tiffany Hernandez
Department: Health and Human Performance

You are being asked to volunteer for this research study. This study is being conducted at the research laboratory in the Department of Health and Human Performance. You were selected as a possible participant because of your inquiry into the study. Volunteers, who are at minimal risk will be eligible to participate in this study, you will be asked to complete PAR-Q and Health status questionnaire to be screened prior to your participation in the study.

Please read this form and ask any questions that you may have before agreeing to take part in this study.

Purpose of the Research Study

The purposes of the study are: 1) to examine the acute effects of circuit training exercises with and without blood flow restriction (BFR) on energy expenditure, heart rate, blood pressure, respiratory exchange ratio, and ventilation rate; 2) To examine the changes in motor unit activation and motor unit action potential conduction velocity in response to exercises performed on stable and unstable surface with and without BFR; 3) to investigate the differences between genders on the previously stated measures.

Number of Participants

15 males and 15 females will take part in this study.

Procedures

If you agree to be in this study, you will be asked to do the following:

a. You will be required to visit the research lab in the Department of Health and Human Performance on 5 separate days. On the first session (approximately 60 min), the initial screening and questionnaires will be completed (10-15 min). After completion of the paperwork; RHR, BP, height, and weight will be performed along with femur length measurement for electromyography (EMG) electrode placement (5-10min). Participants will complete familiarization by being exposed to study procedures and exercises. Participants will be required to initiate the study right after familiarization using a randomly selected condition.

b. During the next four visits, each subject will exercise for 5-10 minutes performing six lower body exercises on a stable and unstable surface with and without BFR. Participants will perform

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all four exercise conditions on different days separated by at least 24 to 48 hours. The total time required to complete each of these sessions is approximately 45 min.

c. The skin will be shaved, lightly abraded, and cleaned with isopropyl alcohol to reduce the electrode-skin impedance. Following skin preparation, Surface EMG electrodes will be placed along the longitudinal axis of the vastus lateralis (VL) and rectus femoris (RF) of the right thigh. The electrode placements on the VL were placed to a mark that was made at 33.3% and RF at 50% of the distance from the lateral femoral epicondyle to the greater trochanter. The ground electrode will be placed over the patella. A Polar Heart Rate monitor will also be placed along the chest. Attachments to the Moxus Modular VO2 System will be placed onto the subject.

d. Determined by a randomized manner, training sessions with BFR or without BFR will be performed during the four different testing days. Each subject will exercise for 5-10 minutes performing six lower body exercises on a stable and unstable surface with and without BFR. The exercises consist of a body squat, super skater on left leg, super skater on right leg, alternating side lunge, squat knee-up left leg, and squat knee-up right leg. Post-exercise resting metabolic rate will be assessed immediately after for 3-5 minutes. During exercise, HR, systolic and diastolic blood pressure, oxygen consumption, respiratory exchange ratio, energy expenditure and muscle function will be continuously monitored.

e. All four visits will last approximately 40-45 minutes. All sessions will be separated by at least 24 to 48hours.

Length of Participation

You will be required to visit the research labs in the Department of Health and Human Performance on 5 separate days for a total time commitment of approximately 4 hours.

This study has the following risks:

There are minimal risks to healthy individuals when performing any of the requirements for this project. However, even though these standard protocols have been approved at numerous other institutions and will be performed by qualified and trained personnel, you should be aware of the following:

a) You may experience slight, temporary discomfort from the inflation of the BFR cuffs around the upper most portions of your thighs. The cuffs will be inflated for about 25 to 30 minutes while you perform BFR circuit training lower body exercises. A properly trained researcher will set the pressure and continuously monitor you while the cuffs are inflated.

b) There is a possibility of temporary muscle soreness occurring 24 to 48 hours after each visit which could be the result of beginning a new exercise protocol.

Benefits of being in the study are:

There is no direct benefit for participation; however the data from this proposed research will provide detailed information on the effectiveness of this novel technique and allow researchers to design training studies to incorporate the unstable surface in a variety of BFR exercises.

Injury

In case of injury or illness resulting from this study, emergency medical services will be contacted. However, you or your insurance company may be expected to pay the usual charge from this treatment. The University of Texas at Brownsville and TSC has set no funds to compensate you in the event of injury.

Confidentiality

In published reports, there will be no information included that will make it possible to identify you without your permission. Research records will be stored securely for 3 years after completion of the study and only approved researchers will have access to the records.

There are organizations that may inspect and/or copy your research records for quality assurance and data analysis. These organizations include Murat Karabulut and the UTB Institutional Review Board.

Costs

There is no cost for participation.

Compensation

You will not be reimbursed for you time and participation in this study.

Rights

Refusal to participate will involve no penalty or loss of benefits to which you are otherwise entitled. You can discontinue participation at any time without penalty or loss of benefits to which you are otherwise entitled.

Voluntary Nature of the Study

Participation in this study is voluntary. If you decline to participate, you will not be penalized or lose benefits or services unrelated to the study. If you decide to participate, you may decline to answer any question and may choose to withdraw at any time.

Waivers of Elements of Confidentiality

Your name will not be linked with your responses unless you specifically agree to be identified. Please select one of the following options

_____ I consent to being quoted directly.

_____ I do not consent to being quoted directly.

Contacts and Questions

You should feel free to ask questions now or at the any time during the study. If you have any questions, you can contact (Dr. Murat Karabulut, Ph.D., University of Texas at Brownsville/TSC, (956) 882-7236, murat.karabulut@utb.edu or Agnelia Tiffany Hernandez, (956) 882-5978, Agnelia.Hernandez@utb.edu). You are encouraged to contact the researcher(s)if you have any questions. If you have concerns or complaints about the research, please contact the student's advisor Dr. Murat Karabulut, Ph.D., University of Texas at Brownsville/TSC, (956) 882-7236, murat.karabulut@utb.edu. If you have any questions about the right of research subjects, contact the Chair of the UTB IRB-Human Subjects at (956) 882-8888 (Dr. Matthew Johnson) or the Research Integrity and Compliance Office at (956) 882-7731 (Lynne Depeault).

You are voluntarily making a decision whether or not to participate. Your signature indicates that, having read and understood the information provided above, you have decided to participate. You will be given a copy of this information to keep for your records. If you are not given a copy of this consent form, please request one.

Statement of Consent

I have read the above information. I have asked questions and have received satisfactory answers. I consent to participate in the study.

Signature Date

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Physician/Doctor Form

University of Texas at Brownsville
Institutional Review Board
Informed Consent to Participate in a Research Study

Project Title:	Hemodynamic and Neuromuscular Responses to Exercises Performed on Stable and Unstable Surface with and Without Blood Flow Restriction
Principal Investigator:	Dr. Murat Karabulut, Agnelia Tiffany Hernandez
Department:	Health and Human Performance

You are being asked to volunteer for this research study. This study is being conducted at the research laboratory in the Department of Health and Human Performance. You were selected as a possible participant because of your inquiry into the study. Please read this form and ask any questions that you may have before agreeing to take part in this study.

Purpose of the Research Study

The purposes of the study are: 1) to examine the acute effects of circuit training exercises with and without blood flow restriction (BFR) on heart rate, blood pressure, and rate of perceived exertion; 2) To examine the changes in motor unit activation and motor unit action potential conduction velocity in response to exercises performed on stable and unstable surface with and without BFR; 3) to investigate the differences between genders on the previously stated measures.

Number of Participants
10 males and 10 females will take part in this study.

Procedures
If you agree to be in this study, you will be asked to do the following:

a. You will be required to visit the research lab in the Department of Health and Human Performance on 5 separate days. All sessions will be separated by at least 24h-48h.On the first session (approximately 40 min), the initial screening and questionnaires will be completed (10-15 min). After completion of the paperwork; RHR, BP, height, and weight will be performed along with femur length measurement for EMG placement (5-10min). Participants will complete familiarization by being exposed to study procedures. Participants will be required to initiate the study right after familiarization using a randomly selected condition.

b. Following skin preparation, surface EMG electrodes will be placed along the longitudinal axis of the vastus lateralis (VL) and rectus femoris (RF) of the right thigh. The electrode placements on the VL were placed to a mark that was made at 33.3% and RF at 50% of the distance from the lateral femoral epicondyle to the greater trochanter. The ground electrode will be placed over the patella. The skin will be shaved, lightly abraded, and cleaned with isopropyl alcohol to reduce the electrode-skin impedance. A Polar Heart Rate monitor will also be placed along the chest.

c. During the four different testing days, each subject will exercise for 10-15 minutes performing six lower body exercises on a stable and unstable surface with and without BFR. During exercise, HR, systolic and diastolic blood pressure, rate of perceived exertion and muscle function will be continuously monitored.

Length of Participation
You will be required to visit the research labs in the Department of Health and Human Performance on 5 separate days for a total time commitment of approximately 5 hours.

This study has the following risks:
You understand there are minimal risks to healthy individuals when performing any of the requirements for this project. However, even though these standard protocols have been approved at numerous other institutions and will be performed by qualified and trained personnel, you should be aware of the following:

a) You may experience slight, temporary discomfort from the inflation of the BFR cuffs around the upper most portions of your thighs. The cuffs will be inflated for about 25-30 minutes while you perform BFR circuit training lower body exercises. A properly trained researcher will set the pressure and continuously monitor you while the cuffs are inflated.

b) There is a possibility of temporary muscle soreness occurring 24 to 48 hours after each visit which could be the result of beginning a new exercise protocol.

Benefits of being in the study are
There is no direct benefit for participation; however the data from this proposed research will provide detailed information on the effectiveness of this novel technique and allow researchers to design training studies to incorporate the unstable surface in a variety of BFR exercises.

Injury
In case of injury or illness resulting from this study, emergency medical services will be contacted. However, you or your insurance company may be expected to pay the usual charge from this treatment. The University of Texas at Brownsville has set no funds to compensate you in the event of injury.

Confidentiality
In published reports, there will be no information included that will make it possible to identify you without your permission. Research records will be stored securely for 3 years after completion of the study and only approved researchers will have access to the records.

There are organizations that may inspect and/or copy your research records for quality assurance and data analysis. These organizations include Murat Karabulut and the UTB Institutional Review Board.

Costs
There is no cost for participation.

Compensation
You will not be reimbursed for you time and participation in this study.

Rights
Refusal to participate will involve no penalty or loss of benefits to which you are otherwise entitled. You can discontinue participation at any time without penalty or loss of benefits to which you are otherwise entitled.

Voluntary Nature of the Study
Participation in this study is voluntary. If you decline to participate, you will not be penalized or lose benefits or services unrelated to the study. If you decide to participate, you may decline to answer any question and may choose to withdraw at any time.

Waivers of Elements of Confidentiality
Your name will not be linked with your responses unless you specifically agree to be identified. Please select one of the following options

_____ I consent to being quoted directly.
_____ I do not consent to being quoted directly.

Contacts and Questions
If you have concerns or complaints about the research, the researcher(s) conducting this study can be contacted at the Department of Health and Human Performance: Dr. Murat Karabulut, Ph.D., University of Texas at Brownsville, (956)882-7236, murat.karabulut@utb.edu or Agnelia Tiffany Hernandez, (956)793-5838, Agnelia.Hernandez@utb.edu. If you have any questions about the right of research subjects, contact the Chairman of the UTB IRB - Human Subjects or the Office of Sponsored Programs at UTB/TSC (956) 882-7849.

You are voluntarily making a decision whether or not to participate. Your signature indicates that, having read and understood the information provided above, you have decided to participate.

Statement of Consent
I have read the above information. I have asked questions and have received satisfactory answers. I consent to participate in the study.

Signature of Physician/Doctor Date

Appendix D.

PAR-Q

Physical Activity Readiness Questionnaire - PAR-Q (revised 2002)

PAR-Q & YOU

(A Questionnaire for People Aged 15 to 69)

Regular physical activity is fun and healthy, and increasingly more people are starting to become more active every day. Being more active is very safe for most people. However, some people should check with their doctor before they start becoming much more physically active.

If you are planning to become much more physically active than you are now, start by answering the seven questions in the box below. If you are between the ages of 15 and 69, the PAR-Q will tell you if you should check with your doctor before you start. If you are over 69 years of age, and you are not used to being very active, check with your doctor.

Common sense is your best guide when you answer these questions. Please read the questions carefully and answer each one honestly: check YES or NO.

YES	NO		
☐	☐	1.	**Has your doctor ever said that you have a heart condition and that you should only do physical activity recommended by a doctor?**
☐	☐	2.	**Do you feel pain in your chest when you do physical activity?**
☐	☐	3.	**In the past month, have you had chest pain when you were not doing physical activity?**
☐	☐	4.	**Do you lose your balance because of dizziness or do you ever lose consciousness?**
☐	☐	5.	**Do you have a bone or joint problem (for example, back, knee or hip) that could be made worse by a change in your physical activity?**
☐	☐	6.	**Is your doctor currently prescribing drugs (for example, water pills) for your blood pressure or heart condition?**
☐	☐	7.	**Do you know of any other reason why you should not do physical activity?**

If you answered

YES to one or more questions

Talk with your doctor by phone or in person BEFORE you start becoming much more physically active or BEFORE you have a fitness appraisal. Tell your doctor about the PAR-Q and which questions you answered YES.

- You may be able to do any activity you want — as long as you start slowly and build up gradually. Or, you may need to restrict your activities to those which are safe for you. Talk with your doctor about the kinds of activities you wish to participate in and follow his/her advice.
- Find out which community programs are safe and helpful for you.

NO to all questions

If you answered NO honestly to all PAR-Q questions, you can be reasonably sure that you can:

- start becoming much more physically active – begin slowly and build up gradually. This is the safest and easiest way to go.
- take part in a fitness appraisal – this is an excellent way to determine your basic fitness so that you can plan the best way for you to live actively. It is also highly recommended that you have your blood pressure evaluated. If your reading is over 144/94, talk with your doctor before you start becoming much more physically active.

DELAY BECOMING MUCH MORE ACTIVE:

- if you are not feeling well because of a temporary illness such as a cold or a fever – wait until you feel better; or
- if you are or may be pregnant – talk to your doctor before you start becoming more active.

PLEASE NOTE: If your health changes so that you then answer YES to any of the above questions, tell your fitness or health professional. Ask whether you should change your physical activity plan.

Informed Use of the PAR-Q: The Canadian Society for Exercise Physiology, Health Canada, and their agents assume no liability for persons who undertake physical activity, and if in doubt after completing this questionnaire, consult your doctor prior to physical activity.

No changes permitted. You are encouraged to photocopy the PAR-Q but only if you use the entire form.

NOTE: If the PAR-Q is being given to a person before he or she participates in a physical activity program or a fitness appraisal, this section may be used for legal or administrative purposes.

"I have read, understood and completed this questionnaire. Any questions I had were answered to my full satisfaction."

NAME ____

SIGNATURE ________________________________ DATE ________________________

SIGNATURE OF PARENT ______________________ WITNESS ________________________
or GUARDIAN (for participants under the age of majority)

Note: This physical activity clearance is valid for a maximum of 12 months from the date it is completed and becomes invalid if your condition changes so that you would answer YES to any of the seven questions.

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Appendix E.

Health Status Questionnaire

University of Texas at Brownsville/TSC

Health Status Questionnaire

Instructions. Complete each questions accurately. All information provided is confidential.

Part 1. Information About The Individual

1. Date___________________

2. Legal Name_____________________________ Nickname_____________________________

3. Mailing Address____

____

Home Phone __________________________Business Phone____________________________

4. Personal Physician Phone ______________________

5. Person to Contact in Emergency Phone _______________________

6. Gender (Circle One): Female Male

7. Date Of Birth: ____/_____/_______ Month/Day/Year

8. Number of hours worked per week: Less than 20 20 - 40 41 - 60 Over 60

9. More than 25% of time on job is spent (Circle all that apply):

Sitting at desk Lifting or carrying loads Standing Walking Driving

Part 2. Medical Information

10. Circle any who died of heart attack before age 50:

Father Mother Brother Sister Grandparent

11. Date of last medical physical exam: ________________(Year)

Last physical fitness test: ______________________(Year)

12. Circle operations you have had:

Back Heart Kidney Eyes Joint Neck

Ears Hernia Lung Other____________________________________

13. Please circle any of the following for which you have been diagnosed or treated by a physician or health professional:

Alcoholism	Cirrhosis, Liver	Hearing Loss	Neck Strain
Anemia, Sickle Cell	Concussion	Heart Problem	Obesity
Anemia, Other	Congenital Defect	High Blood Pressure	Phlebitis
Asthma	Diabetes	Hypoglycemia	Rheumatoid Arthritis
Back Strain	Emphysema	Hyperlipidemia	Stroke
Bleeding Trait	Epilepsy	Infectious Mononucleosis	Thyroid Problem
Bronchitis, Chronic	Eye Problems	Kidney Problem	Ulcer
Cancer	Gout	Mental Illness	

Other____

14. Circle all medicine taken in last 6 months:

Blood Thinner	Diuretic	High Blood Pressure Medication
Diabetic Pill	Epilepsy Medication	Insulin
Digitalis	Heart-Rhythm Medication	Nitroglycerin

Other____

15. These health symptoms may require medical attention if they occur frequently. Circle the number indicating how often you have each of the following:

5 = Very Often 4 = Fairly Often 3 = Sometimes 2 = Infrequently 1 = Practically Never

a. Cough up blood	d. Leg pain	g. Swollen joints
1 2 3 4 5	1 2 3 4 5	1 2 3 4 5
b. Abdominal pain	e. Arm or shoulder pain	h. Feel faint
1 2 3 4 5	1 2 3 4 5	1 2 3 4 5
c. Low back pain	f. Chest pain	i. Dizziness
1 2 3 4 5	1 2 3 4 5	1 2 3 4 5

j. Breathless with slight exertion

1 2 3 4 5

Part 3. Health-Related Behavior

16. Do you now smoke? (Circle one) Yes No

17. If you are a smoker, indicate number smoked per day:

Cigarettes: 40 or more 20 - 39 10 - 19 1 - 9

Cigars or pipes only: 5 or more or any inhaled Less than 5, non inhaled

18. Do you exercise regularly? (Circle one) Yes No

19. How many days per week do you normally spend at least 20 minutes in moderate to strenuous exercise?

0 1 2 3 4 5 6 7 days per week

20. Can you walk 4 miles briskly without fatigue? (Circle one) Yes No

21. Can you jog 3 miles continuously at a moderate pace without discomfort? (Circle one) Yes No

22. Weight now__________ lb. One year ago_____________ lb. Age 21_________ lb.

23. List everything not already included on this questionnaire that might cause you problems in a fitness test or fitness program:

____

____

____

Appendix F.

Data Collection Sheet

Familiarization Day

HEMODYNAMIC AND NEUROMUSCULAR RESPONSES TO EXERCISES PERFORMED ON STABLE AND UNSTABLE SURFACE WITH AND WITHOUT BLOOD FLOW RESTRICTION

Descriptive Data Collection Sheet - Familiarization

Name:______________________________	Gender: M / F	Date: ___/___/___
Resting BP:____ / _____	Age (yrs):_________	Height (cm):_________
Resting HR:________	Weight (kg):_________	BMI(kg/m2):_________

CONTACT INFORMATION	
Primary Phone #:	
Alternate Phone #:	
E-mail address:	

(Left) EMG Electrode Placement	(Right)	Thigh Circumference & KAATSU Measurements
Femur Length (cm): _________	Femur Length (cm): ______	Right Leg (cm): ___________
VL Placement at (cm): _________	VL Placement at (cm): ______	TRP (mmHg): ______________
RF Placement at (cm): _________	RF Placement at (cm): ______	(<45–50 cm = 120 mmHg; 51–55 cm = 150 mmHg; 56–59 cm = 180 mmHg; and ≥60 cm = 210 mmHg)

[redacted]

Familiarization with Exercise

Exercises Performed		Sets	Reps
1)	Body Squat	2	20
2)	Super Skater (L)	2	10
3)	Super Skater (R)	2	10
4)	Alternating Side Lunge	2	20
5)	Knee Up (L)	2	10
6)	Knee Up (R)	2	10

Condition			Surface	
Blood flow restriction	No blood flow restriction	1 - No BFR on Stable	Stable	Unstable
		2 - No BFR on Unstable		
		3 - BFR on Stable		
		4- BFR on Unstable		

Testing Day

Name: ______________________________	Condition Order:	Exercise Order: ___/___/___/___/___/___		Gender: M / F
Date: ___/___/___	Age (yrs):______	Weight (kg):_________	Height (cm):__________	Resting HR:______	Resting BP:____ / _____

1 - No BFR on Stable	
2 - No BFR on Unstable	
3 - BFR on Stable	
4- BFR on Unstable	

EMG Electrode Placement	TRP
Femur Length (cm): ___________	
VL Placement at (cm): ____________	
RF Placement at (cm): ____________	

	Exercises Performed	Sets	Reps
1)	Body Squat (S)	2	20
2)	Super Skater Left (SL)	2	10
3)	Super Skater Right (SR)	2	10

	Exercises Performed	Sets	Reps
4)	Alternating Side Lunge (A)	2	20
5)	Knee Up Left (KL)	2	10
6)	Knee Up Right (KR)	2	10

	Exer.	Y/N	RPE	HR	Comments
Set 1					

	Exer.	Y/N	RPE	HR	Comments
Set 2					

Exercises BP (immediately after) :____ / _____
Exercises BP (3 min after):____ / _____
Exercises BP (4 min after):____ / _____
Exercises BP (6 min after):____ / _____
Exercises BP (8 min after):____ / _____